Polyphase Transmission

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THE JOURNAL OF
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*Polyphase Transmission.**

BY CHAS. F. SCOTT.

THE alternating current when first introduced for lighting presented many new problems to the electrical engineer. Numerous difficulties and dangers were predicted by the theorist, but in ordinary service most of these have fortunately lain dormant. These difficulties are apt to appear, however, when alternating current work is attempted on a large scale. The introduction of large units, heavier currents, higher potentials or power service is apt to increase the effects of self-induction and capacity, so that they now demand careful consideration. The impetus that electrical engineering is receiving from the introduction of the polyphase system, which brings with it large units and long distances, naturally directs attention to the general problem of alternating current transmission and distribution.

ALTERNATING-CURRENT PROBLEMS.

A complete and exhaustive solution of this problem is by no means a simple one, and the attempted solutions generally lead to formulae and diagrams which are possibly even more perplexing than the phenomena. If even the electrician who devotes all his energy to new problems can scarcely keep abreast of the times, it is not surprising that the practical engineer and station manager become perplexed and confounded at the apparently erratic phenomena observed in practice or described in print. Theoretical articles appear on variation in wave form, harmonics, so-called Ferranti effects, increased resistance in conductors with alternating currents, hysteresis, peculiar magnetic circuits, resonance, oscillations, lag, capacity, self-induction. Many of these articles, although evidently intended to be of service in engineering, show apparently no adequate appreciation of the practical bearing and relation of the subjects treated. Consequently, the average engineer becomes bewildered and perplexed, and concludes that theoretical explanations are of little value to the practical man. There are, however, many problems of great practical importance which admit of fairly simple statement and explanation. The particular element to be considered in the present paper is the transmission circuit.

EXPERIMENTS ILLUSTRATING SELF-INDUCTION.

One of the fundamental characteristics of alternating current work is self-induction. The effect of self-induction is most readily shown by a simple experiment. A wire having a resistance of 10 ohms may be wound in a coil. Ten volts will send a continuous current of 1 ampere through this coil. An alternating current of a certain frequency will require 50 volts for forcing 1 ampere through the same wire (Fig. 1A). (In the diagrams the numbers above the circuit are for continuous current and those below are for alternating current.) If a 1-ampere 50-volt lamp be placed in series with the coil and a current of 1 ampere be passed through the two in series, the E. M. F. required for continuous current is 10 volts on the coil and 50 volts on the lamp, or 60 volts across the circuit, and the E. M. F. required for alternating current is 50 volts across the coil and 50 volts across the lamp, which gives, not 100 volts, but 78 volts measured across the two in series (Fig. 2). If two

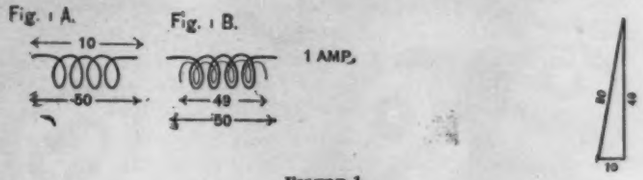


FIGURE 1.

lamps be placed in multiple and connected in series with the coil, 2 amperes will require for continuous current 20 volts on the coil and 50 volts on the lamps, or 70 volts across the circuit. For alternating current the E. M. F. on the coil is 100 volts and on the lamps 50 volts, and on the circuit across the two in series the E. M. F. is 120 volts (Fig. 3).

The two lamps which are in multiple may be placed in series with a small coil. This small coil may be so proportioned in its number of turns and resistance that an E. M. F. of 50 volts will send 1 ampere alternating current through the combination (i. e., the small coil and the lamps), and a continuous current of 1 ampere would be caused by 35 volts. This combination may be treated as a unit and may be used to replace the single lamp in the above test (Fig. 2). If this combination be placed in series with the first coil (the one used in the first experiment) the E. M. F. required for sending the continuous current through the circuit will be 10 volts on the coil and 45

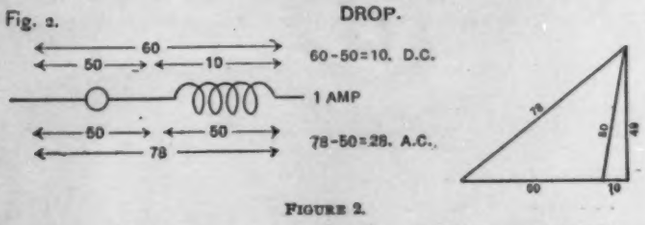


FIGURE 2.

volts on the circuit. If the alternating current of 1 ampere be sent through the circuit, 50 volts will be required across the combination, and 50 volts across the coil, the same as with the single lamp, but the E. M. F. across the circuit is no longer 78 volts, but has increased to 95 volts (Fig. 4).

The important facts to be noted in these experiments are: (1) That the sum of the alternating E. M. Fs. on the elements connected in series is greater than the E. M. F. required upon

*A paper read before the National Electric Light Association, March 1, 1894, and revised by the author, 1899. Published through the courtesy of the Westinghouse Electric and Manufacturing Company.

the terminals of the circuit; (2) that the alternating E. M. F. for supplying the lamps in series with a coil is greater than the continuous E. M. F., and (3) that the difference between the two becomes greater as the number of lamps is increased (Figs. 2 and 3). It is also to be noted (4) that if the same alternating current be supplied through a coil, first to a lamp alone and then to a combination including lamps and a coil, a higher E.

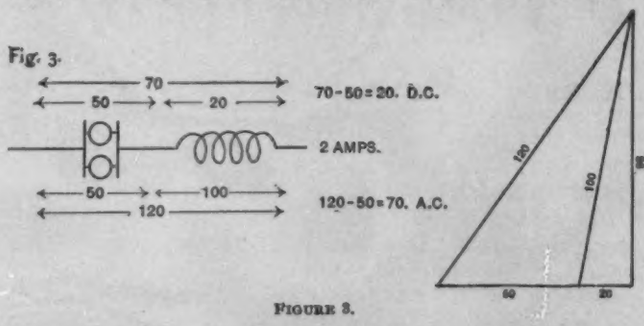


FIGURE 3.

M. F. is required when the combination is used (Figs. 2 and 4).

These relations, which seem rather perplexing, may be illustrated in a very simple way by diagrams. In the case of the coil alone, in which 50 volts are required for producing 1 ampere alternating current and 10 volts for 1 ampere continuous current, these two E. M. Fs. may be represented by the hypotenuse and one side of the familiar right angle triangle. The remaining side represents the counter E. M. F. in the coil. If a second wire had been found in this coil in parallel with the first it would be found that when 1 ampere is passing there is an E. M. F. on the terminals of the second, or idle wire, of 49 volts (Fig. 1B). This E. M. F. is caused by the field produced by the alternating current. An equal E. M. F. is, of course, induced in the wire carrying the current, as the two wires occupy virtually the same position. This counter E. M. F. is seen to correspond with the third side of the triangle. Suitable measurements would show that this counter E. M. F. is not coincident with the current through the coil, but that its maximum value occurs when the current is passing through its zero. This relation is shown in the diagram by the 90-degree relation of the lines representing counter E. M. F. and the volts required for sending continuous current through the line. Triangular diagrams are also given in connection with a number of the other figures. The relation between the lines in the triangle and the voltages in the figures showing the coils and lamps can be readily seen, as the numbers denoting the voltages are given in both cases.

SELF-INDUCTION IN CIRCUITS.

An ordinary circuit may be considered as a choke coil in which there is a single turn. The action in this case is very similar to that illustrated above with a coil of many turns. The effect of self-induction in a circuit may be most readily

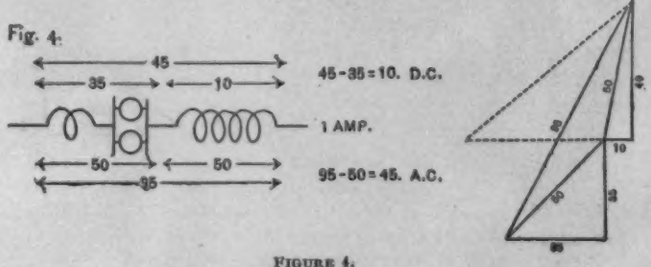


FIGURE 4.

understood by some simple diagrams. A current of say 5 amperes is delivered at 100 volts over a circuit of one-fifth of an ohm resistance. The self-induction of the circuit is such that 5 amperes generate a counter E. M. F. of 10 volts. Both continuous and alternating currents are used, and the generator E. M. F. is in each case adjusted to give 100 volts at the load. The load consists, first, of five incandescent lamps. A coil of high self-induction is then added, which increases the current from 5 to 5.1 amperes. One of the lamps is then cut out and replaced by coils of such a self-induction as to give a total of 5 amperes. Then all of the lamps are cut out and coils substituted of such a number as to take 5 amperes at 100 volts. The E. M. F. required on the generator and the resulting drop, or difference of E. M. F., at the dynamo and at the load are given in the diagrams and in the following table:

	Continuous Current.	Alternating Current.			
	Fig. 5.	Fig. 6.	Fig. 7.	Fig. 8.	Fig. 9.
Current in line	5	5	5.1	5	5
Current in lamps	5	5	5	4	0
Current in coils	0	0	1	3	5
E. M. F. on load	100	100	100	100	100
E. M. F. on line	1	10	10	10	10
E. M. F. on generator	101	101.5	102.5	106	110
Drop—total	1	1.5	2.5	6	10

It is to be noted that with exactly the same circuit for supplying five lamps with the same amperes at the same E. M. F.

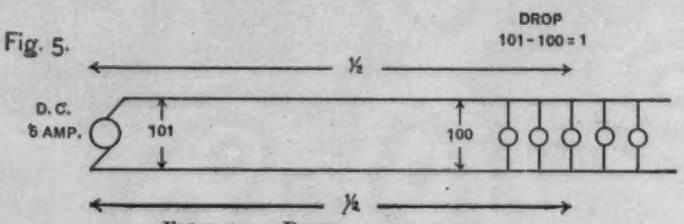


FIGURE 5.—DROP = 101 − 100 = 1.

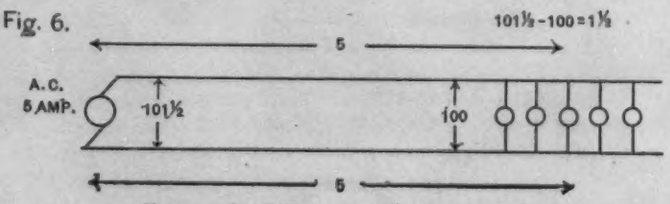


FIGURE 6.—DROP = 101½ − 100 = 1½.

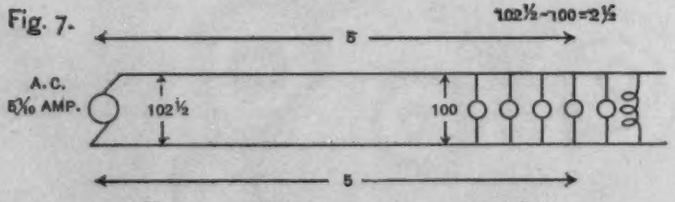


FIGURE 7.—DROP = 102½ − 100 = 2½.

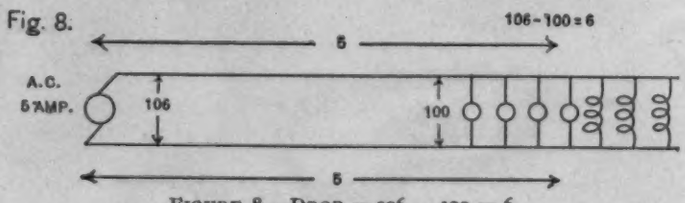


FIGURE 8.—DROP = 106 − 100 = 6.

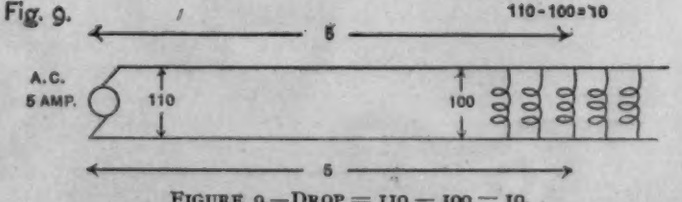


FIGURE 9.—DROP = 110 − 100 = 10.

there is an increase of drop between generator and load when continuous current is replaced by alternating current. This drop is much less than the volts required for sending the alternating current through the line, and it, moreover, increases enormously as the load becomes even slightly inductive. Thus, when the current is increased only 2 per cent. (from 5 to 5.1 amperes, Figs. 6 and 7) by the addition of inductive load to the lamp load, the increase of drop due to self-induction is increased from ½ per cent. to 1½ per cent., or an increase of threefold. When the load consists of four lamps and coils are added in multiple to take a total of 5 amperes from the generator, or the same as that taken by the five lamps, the drop is four times the drop when five lamps alone are in circuit. If the remaining four lamps be replaced by coils, the drop does not increase in proportion, but from 6 to only 10 per cent. The effect, therefore, of a slight self-induction in the load causes a much greater proportional drop than the presence of a large self-induction. A counter E. M. F. of 10 per cent. is not at all likely to occur in a 100-volt line carrying small current. The figures given, however, serve as an illustration of the percentage variations which are possible in other parts of the system.

Fig. 10.

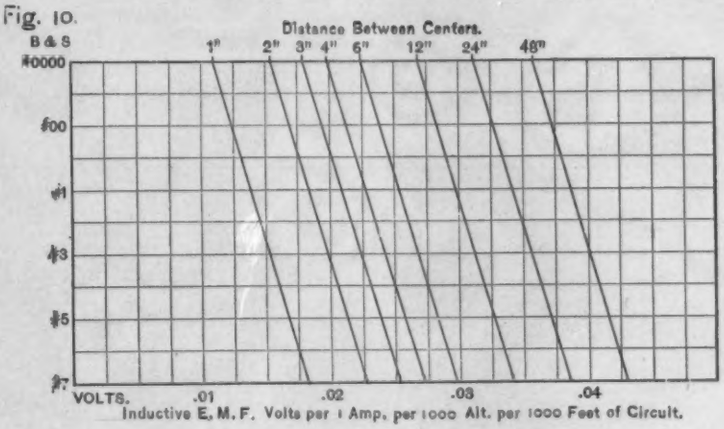


FIGURE 10.

DROP IN CIRCUITS.

The word "drop" in continuous current calculations has a perfectly well defined meaning. In the case of the five lamps which take 5 amperes at 100 volts through a circuit of one-fifth of an ohm, as illustrated in Fig. 5, the drop is: (1) the difference between the E. M. F. at the generator and at the lamps, or 1 volt, which is 1 per cent.; (2) it is the E. M. F. required for sending the current through the line; this is equal to the current multiplied by the resistance, and is the E. M. F. which would be required for sending the current through the line if the load be short circuited; (3) a drop of 1 per cent. means also that the energy lost in the line is 1 per cent. of that delivered by the generator; (4) a loss of 1 per cent. in the line also signifies that the energy delivered is 1 per cent. less than that suplied by the generator.

In alternating current work the same uniformity does not exist; for example, in the experiments with the same five lamps and the same line: (1) the generator pressure was 101½ volts, or 1½ per cent. higher than that of the lamps; (2) the E. M. F. required for sending a current through the line short circuited is 10 volts, or 10 per cent.; (3) the energy lost in wires is C^2 R, or 5 watts, which is 1 per cent. of the energy when five lamps are supplied. If four lamps and low resistance coils are connected to the circuit, the energy delivered is, say, 400 watts and the loss is 1¼ per cent.; (4) if the coils alone are supplied and their combined resistance is equal to that of the circuit, or one-fifth of an ohm, then the losses in load and line are equal and the actual line loss is 50 per cent. The apparent energy at the generator is 550 watts (110 volts and 5 amperes) and the apparent energy delivered is 500 watts (100 volts and 5 amperes), so that the apparent loss is 9 per cent.

It is therefore evident that the several elements commonly referred to as drop or per cent. loss with continuous current are so modified when alternating current is used that it is possible for no two of them to have the same value. Moreover, with alternating current, none of these elements may have the same per cent. value as that for continuous current on the same circuit.

LOSS AND REGULATION.

The two vital factors in the line are loss and regulation. The losses are C^2 R, and should be expressed in watts or horsepower, or as a per cent. of the energy delivered to the line. The practical point in regulation is the difference in E. M. F. at the generator and at the load. When these two factors are known, it is generally immaterial what E. M. F. might be required for sending current through a short circuited line. The word "drop" is applied to the difference in E. M. F. between the generator and the load. The regulation is generally expressed in per cent. of generator E. M. F., but in this paper the E. M. F. at the load will be considered 100 per cent., as this is the element to be kept constant while the E. M. F. of the generator is variable, depending upon the load and other elements.

Regulation in a circuit is in general determined by three elements—the resistance, the counter E. M. F. of the circuit and the power factor of the load. The counter E. M. F. of a line depends upon the size of wire and the distance between wires, and it increases directly as the length of the circuit, the current and the alternations. The counter, or inductive, E. M. F. of a line has been calculated for a number of cases, which are likely to occur in practice, and the results are given in Fig. 10.

DROP IN ALTERNATING CIRCUITS.

The drop, or difference of potential between generator terminals and the load terminals, due to the counter E. M. F. of the line, depends, as has been shown, upon the self-induction of the load. The latter is best expressed by a power factor, or a factor by which the product of the amperes and volts, or the apparent energy, must be multiplied to give the true power in watts. The power factor for incandescent lamps is 1.00, as the aparent energy is equal to the true energy. The power factor for transformers loaded with incandescent lamps is usually over .99. The factor for unloaded transformers varies from

Fig. 11.

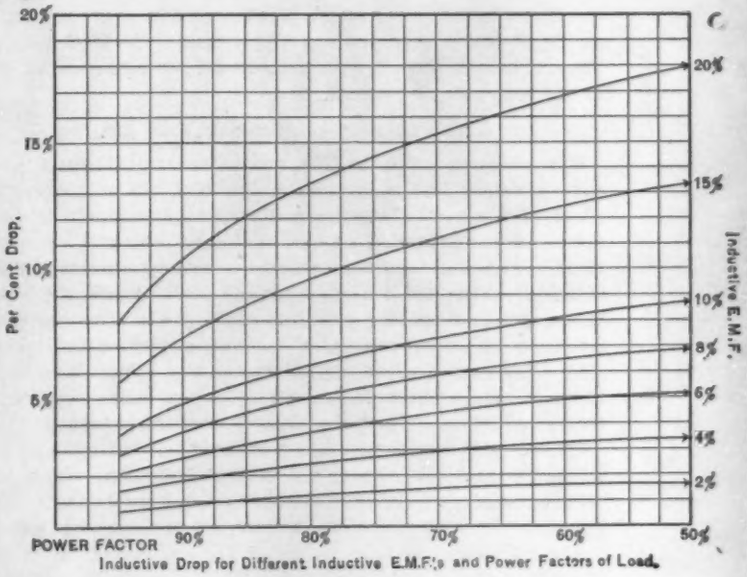


FIGURE 11.

.50 to .80, and in open magnetic circuit transformers, notably the "hedgehog," the factor may be as low as .05. The drop due to self-induction on the line (which, plus the ohmic drop, will give approximately the total drop), corresponding to various power factors of the load, is given in Figs. 11 and 13. The curves show that if the power factor be 100 per cent., as it is with incandescent lamps, the inductive drops for various counter or inductive E. M. Fs. are .02 per cent. for 2 per cent.; .08 per cent. for 4 per cent.; .18 per cent. for 6 per cent.; .32 per cent. for 8 per cent.; .5 per cent. for 10 per cent.; 1.2 per cent. for 15 per cent., and 2 per cent. for 20 per cent. The curves show that the drop increases very rapidly at first if the power factor becomes less. These relations may be elegantly determined by a simple diagram on section paper ruled in tenths. Draw an arc through a quadrant with a radius of 100. Graduate the horizontal and the vertical scales, beginning with 0 at the center and reaching 100 at the circle. On the horizontal scale find the point corresponding to the power factor of the load, follow up the vertical line to the circle. This line represents the counter E. M. F. of the load and its length read on the vertical scale gives the counter E. M. F. of the load in per cent. of the E. M. F. on the terminals of the load. From the intersection with the arc of the circle proceed horizontally a distance corresponding to the effect of the resistance of the line, i. e., to the E. M. F. required for sending an equal continuous current through the line resistance, expressed in per cent. of the E. M. F. upon the load. From this point proceed upward a distance equal to the counter E. M. F. of the line expressed in per cent. of the E. M. F. on the load.

A line from the center to the upper end of this vertical represents, in direction and magnitude, the E. M. F. which must be impressed on the circuit. If from the same center an arc be drawn through this point to the base, the scale divisions on the base between the two arcs measure the total drop caused by the line, in terms of the E. M. F. at the load. This construction is shown in Fig. 12 for two cases. The E. M. F. corresponding to the effect of the resistance of the line, or the "resistance volts," is 2 per cent. in each case, and the counter E. M. F., or the "reactance volts," is taken as 10 per cent. in each case. In one example the power factor is taken as 1.00 or 100 per cent., and in the other case as 0.8 or 80 per cent. The total drop in the first case is seen to be a trifle over 2 per cent., and in the second case about 8 per cent.

SELF-INDUCTION IN TRANSFORMERS, ETC.

Self-induction exists in line, generators, transformers, secondary wiring, and sometimes in the load. In each case the effect of the self-induction upon regulation depends largely upon the self-induction of the total load which it supplies. Thus, the regulation of a generator depends upon the trial self-induction of the line, transformers and load. Again, the regulation of line supplying transformers depends upon the self-induction of the transformers, as well as that of the useful load. The same analysis and diagrams which have been used above in connection with the line will apply to the transformers and approximately to the regulation of the generator.

An ordinary transformer has a primary self-induction and a secondary self-induction and a mutual induction, which become a ready source of very complicated and perplexing analysis when the complete action is described in theoretical terms. Practically, however, the action of the self-induction in the transformer may be expressed in a very simple way, and it is readily seen that this self-induction has a very important bearing upon the regulation of the transformer. The regulation of the transformer is very similar to that of a line, as explained above. If the secondary coil be short circuited, the E. M. F. on the primary may be adjusted so that the normal full load current passes through the apparatus. This E. M. F. is analogous to the E. M. F. required for sending current through a short circuited line, and in ordinary transformers is practically equal to the counter E. M. F. of self-induction, and may be considered equal to it.

A transformer may be taken for experiment in which the E. M. Fs. are 1,000 volts and 100 volts. If 5 volts, or ½ per cent., is required for sending through the primary a continuous current equal to the normal full load current of the transformer, and if a similar E. M. F. in the secondary is ½ a volt, or ½ per cent., then the ohmic loss in the transformer is 1 per cent. and the drop in pressure at the secondary terminals between no load and full load will be 1 per cent. if the self-induction be negligible. If, however, there is a self-induction so that 100 volts, or 10 per cent., is required, at a given frequency, for sending an alternating current of the normal strength through the primary when the secondary is short-circuited,

Fig. 12.

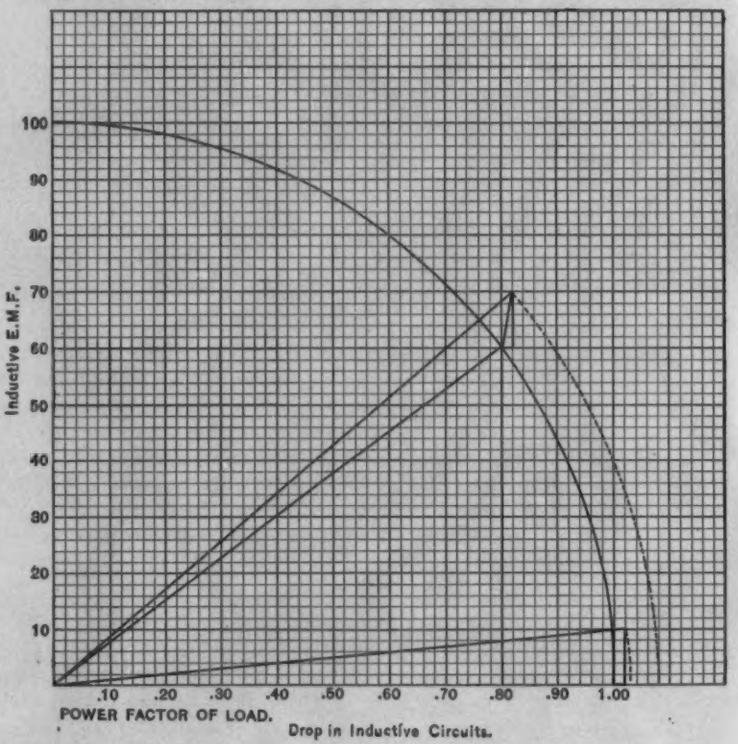


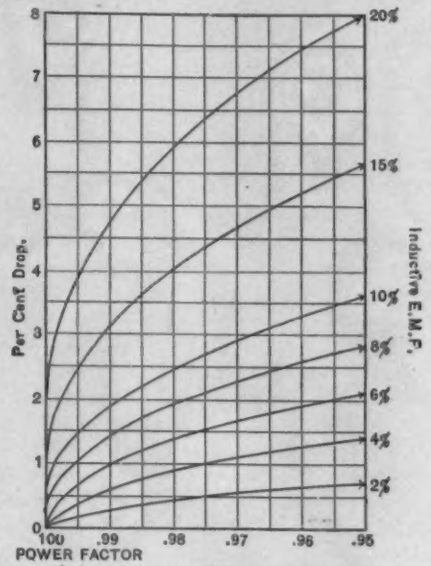
FIGURE 12.

then the drop in pressure is in general greater than 1 per cent., depending principally upon the character of the load. The load may be non-inductive, as lamps, or it may be more or less inductive. The experiments described above, in which a line had the same per cent. ohmic and inductive characteristics as the transformer just described, apply to the transformer as well as to the line. The drop on such a transformer, therefore, may vary from 1½ to 10 per cent. when delivering its rated current. Arc lamps, or fan motors, will produce a very much greater drop than incandescent lamps. The power factor of an alternating current arc lamp varies considerably, but in a number of cases has been found between 85 and 90 per cent. The drop, when incandescent lamps are replaced by arc lamps on the transformer just described, increases from about 1½ to 5 or 6 per cent.

A secondary line, if it carry a large current, may have a counter E. M. F. of several volts. This may not be enough to increase appreciably the drop in the line between the transformer terminals and incandescent lamps. But the transformer, however, delivers current to the secondary circuit and to the lamps, so that the regulation of the transformer may be

affected by the self-induction of the secondary circuit. Cases have occurred in which transformers of a very old type possessing high self-induction were supplying very large secondary currents and the resulting drop in the transformers was increased several per cent. For example, a circuit of No. 0000 B. & S. wire supplying 100 amperes to 50-volt lamps at a dis-

Fig. 13.



Inductive Drop for Different Inductive E.M.F's and Power Factors of Load.

FIGURE 13.

tance of 100 feet has an ohmic drop of 2 per cent. The constant for counter E. M. F. of this circuit, if the wires be 6 inches apart, is .022. The volts at 16,000 alternations are .022x 100x.1x16 equal 3.52, or 7 per cent. of 50 volts. The inductive drop in the line corresponding to 7 per cent. is .25 per cent. The power factor of the aggregate service of the transformer is the second side of a right angle triangle, of which 7 is one side and 100 is the hypotenuse. This is 99.7, which is the power factor of the total load on the transformer. If the inductive E. M. F. in the transformer be 10 per cent., the inductive drop is 1.2 per cent.; if 20 per cent., the inductive drop is 3.4 per cent., and if 30 per cent., the inductive drop is 7 per cent. The aggregate drop in the transformer and secondary circuit in the latter case would be, say, 2 per cent. for ohmic drop in transformer, 2 per cent. ohmic drop in line, 7 per cent. inductive drop in transformer, and .25 per cent. inductive drop in line, or a total of 11.25 per cent. The necessary ohmic drop is 4 per cent. and the inductive drop resulting from self-induction in transformer and line is therefore 7.25 per cent. If the number of alternations be reduced to 7,200, the inductive drop would be reduced from 7.25 per cent. to 1.5 per cent.

MUTUAL INDUCTION.

If two circuits be run on the same pole line they act as a transformer, in which one circuit carrying current may act as a primary and induce E. M. F. in the other as a secondary. If the latter circuit is connected with the same dynamo and is delivering current, its E. M. F. will be slightly raised or slightly lowered by the effects of the first circuit. Conversely, the second circuit will have similar effect upon its neighbor, raising or lowering its pressure by a slight amount. If the two circuits be connected to different dynamos which are running at slightly different speeds, then the E. M. F. induced by one circuit upon the other will sometimes increase and at other times decrease the E. M. F. of the circuit, depending upon whether the two currents at a given moment are flowing in the same or in opposite directions. This fluctuation may cause variations in the intensity of the lights supplied. It is readily detected in the service of some central stations, and is of course most marked at time of full load, as the induction of one circuit upon another depends upon the strength of current carried. The fluctuation due to this action may be readily distinguished from that due to slipping of belts or irregularity in engine speed, as the induction effect is due to the difference in alternations between two machines, and the speeds of the two machines are apt to vary slightly from time to time, giving a gradual variation in the rate of fluctuation of the lamps. The fluctuation due to mutual induction of lines occurs only at the end of the line, and is not observed in the station, while the other causes affect the station lights also. The number of volts E. M. F. set up in one circuit by a parallel circuit depends upon the current, the frequency, the distance which the lines are parallel and upon the relative positions of the four conductors. The distance between wires may be six inches or six feet without affecting the mutual induction, provided the relative positions be unchanged. Several dispositions of circuits are shown in the accompanying Fig. 14, and the number of volts per thousand feet at 7,200 and at 16,000 alternations which are induced in either circuit by one ampere in the other are given in connection with each figure. The number of volts required for producing objectionable flickering in the light depends upon the voltage of the lamps in service, the efficiency at which they are run and the general surroundings in which they are placed, notably the relation of lamps to reflectors, white walls, etc., and the general disposition of the customer.

An E. M. F. of ½ per cent. induced in one circuit by another can in some cases be detected, and usually more than 1 or 2 per cent. will cause objectionable flickering.

METHODS OF REDUCING INDUCTION.

The mutual induction is reduced by bringing the wires in each circuit close together and separating the circuits. The

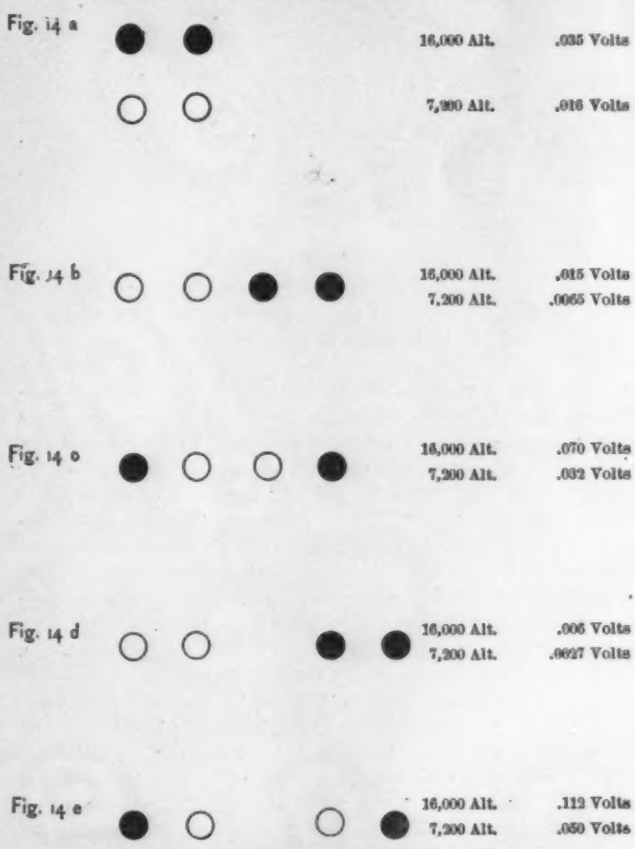


FIGURE 14.—VOLTS IN ONE CIRCUIT INDUCED PER 1000 FEET PER AMPERE IN THE SECOND CIRCUIT.

effect of this mutual induction may be neutralized by crossing one of the lines at its middle point, so that induction in the first half of the line is counteracted by the induction in the second half. It is readily noted that the effect of self-induction in a circuit is reduced as the wires are brought close together, or if each conductor be divided into several wires in multiple and separated. The effect of self-induction is diminished as the number of alternations is reduced. The following points are also to be noted in connection with the inductive drop: If the power factor be nearly 100 per cent., the inductive drop increases as the square of the counter E. M. F. If the E. M. F. of the circuit be increased and the same power be delivered over the same circuit, the per cent. counter E. M. F. decreases as the square of the E. M. F. delivered, and the inductive drop decreases approximately as the fourth power. If the number of alterations be decreased, the counter E. M. F. decreases directly and the inductive drop decreases as the square. The inductive drop at 7,200 alternations is less than one-fourth of that for 16,000 alternations for ordinary power factors.

CAPACITY IN LINES.

The static capacity in ordinary lines is usually small, and its effect is not of importance unless the line be very long or the pressure be very high. The general effect of capacity in the line or of connecting condensers to the line is to lessen the current from the generator which is required for supplying inductive load and to neutralize the drop due to self-induction. The use of condensers for this purpose may lead to very considerable gains in circuits where the self-induction of line or of load becomes considerable. If an inductive circuit or transformer supply current to condensers, the E. M. F. may increase instead of decreasing, as it does with inductive load.

Fig. 15.

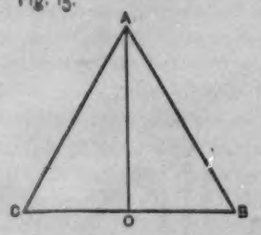


FIGURE 15.

ON POLYPHASE CIRCUITS.

The subjects which have so far been considered apply to single phase as well as to polyphase circuits. The effects of self-induction will be brought to the attention of the electrical engineer much more prominently in connection with polyphase work, however, because the larger alternating current enterprises will be carried out with the polyphase system, and power work involving variable power factors will be a large element in this system. There are, in addition, several problems which relate distinctively to polyphase working. One of these is the most suitable number of phases to be used. The two-phase system and the three-phase system are both in operation, and while it is admitted by the adherents of each system that there is no fundamental difference between them, yet each has specific characteristics giving particular advantages.

The self-induction of a three-phase circuit for transmitting a given amount of power under similar conditions of E. M. F. is the same as that which is incident to the two-phase four-wire circuit, if the same size of wire is used in both cases and the wires of the three-phase circuit are equally distant from one another, and this distance is equal to that between the wires in each phase of the two-phase circuit. This renders the calculation of the drop due to the self-induction of the three-phase circuit quite a simple matter. The loss and the regulation are the same as would be obtained in transmitting half the power at the same power factor over two of the wires of the three-phase circuit. The advantage of the three-phase transmission over single-phase transmission is therefore evident, as the addition of the third wire, involving an increase of 50 per cent. in the weight of the conductor, enables twice the power to be transmitted with the same efficiency and regulation. A corresponding gain is, of course, obtained over the two-phase system, as it is in effect the same as two ordinary single-phase circuits in so far as the efficiency of conductors is concerned.

A further advantage of three instead of four wires is the reduced cost of insulators and line construction, the reduced losses due to leakage and the lessened liability to break-down, resulting from the fewer insulators.

An important point of difference between the two systems is the effect of loading one branch of the system more heavily than the others, as is common in incandescent lighting. One of the statements which remains uncontroverted in Professor Forbes' recent comprehensive and remarkable paper upon the "Electrical Transmission of Power at Niagara Falls" is in reference to the difference of regulation in dynamos for two-phase and for three-phase alternating currents. He gives the result of tests showing that the circuits of a three-phase generator differ greatly in pressure if they are not equally loaded, and states that, having considered these points, the directors of the company determined to reject the three-phase system. These results agree fairly well with tests which I have made. The relative regulation of the two types depends very largely, of course, upon the design of the machines. Other things being equal, the inequality in the voltages on the different phases of a generator, when the circuits are unequally loaded, is much greater in the three-phase than it is in the two-phase type.

If independent regulation of circuits is necessary, one circuit can be given the proper pressure directly from the dynamo and the other circuits may be raised or lowered, as may be required. This involves apparatus for regulating two circuits if the station be operated by the three-phase system, and only one circuit if the two-phase system is in use.

In a system where incandescent lighting is to be a prominent feature, or where load of any kind may be required upon one circuit and not on the other, the two-phase system has, therefore, a decided advantage in station regulation over the three-phase system. Another advantage of a two-phase circuit is that the load is separated into two divisions instead of three divisions, which is in general much simpler. A further advantage of the two-phase is in the reduction of potential for motors.

Fig. 16.

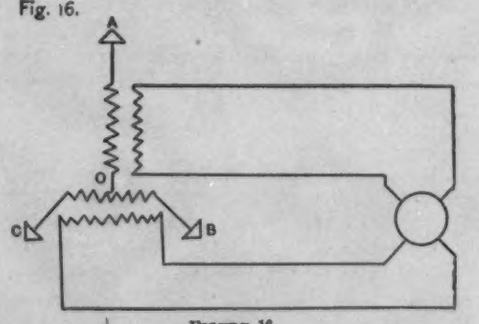


FIGURE 16.

Two transformers are sufficient in the two-phase system, whereas three transformers are commonly used in the three-phase system. The two transformers which would be required for small motors will cost considerably less than the three transformers which would be required on the three-phase system, and the loss in transformation will be much less, as there is not much difference in the cost of small transformers of

slightly different sizes, and the large sizes are more efficient. The ease and simplicity of installation is also a gain for the two-phase arrangement.

THE SCOTT SYSTEM.

In considering the advantages of the three-phase system for transmission and of the two-phase system for distribution, it occurred to me that a combination of the two systems might secure the advantages of both in a combined system, and I have worked out a simple and effective method of accomplishing this result. It is well known that if two E. M. Fs. differing in phase be connected in series that the resulting E. M. F. will, in general, differ in value and in phase from either of its components. If two E. M. Fs. differing in phase 90 degrees be connected in series the resultant E. M. F. is represented in direction and magnitude by the hypotenuse of a right angle triangle, of which the two sides are the two component E. M. Fs. Thus, in Fig 15, if *A O* and *O B* are two E. M. Fs. at right angles, and these E. M. Fs. be connected in series, the resultant is the line *A B*, of different phase from either of the components. It is a simple matter to so proportion the components that *O B* is equal to one-half of *A B*, as shown in the diagram. In a similar manner it is readily seen that the same E. M. F., *O A* may be combined with *O C*, which differs from it by 90 degrees (but is equal and opposite to *O B*) in such a way as to give *A C* equal to *A B*, but differing in direction. *B O* and *O C* added together give *B C*. The E. M. F., *B C*, may therefore be combined with the E. M. F., *A O*, at right angles to it, in such a way as to give additional E. M. Fs., *A B* and *C A*, which, in connection with *B C*, give three equal E. M. Fs. 120 degrees apart. This is the relation of E. M. Fs. in the three-phase system.

Fig. 17.

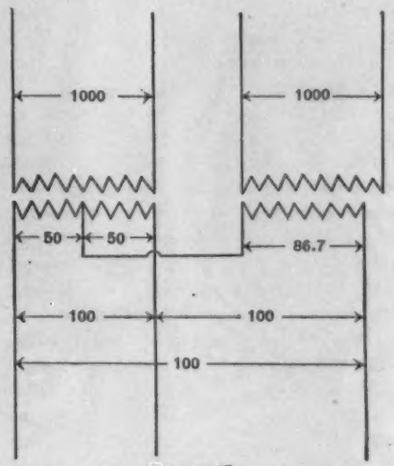


FIGURE 17.

Fig. 18.

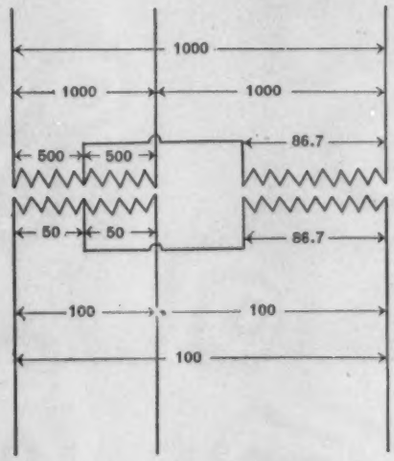


FIGURE 18.

The application of this arrangement to transformers is illustrated in the accompanying Figs. 16 and 17. The primaries of two transformers are connected to a generator giving two-phase current. The secondary E. M. Fs., therefore differ 90 degs. One secondary is made equal to 100 turns and a loop is brought out at its middle point, giving 50 turns at each side. The second secondary has 87 turns, which is approximately equal to 50 multiplied by the square root of 3. One end of the secondary circuit is connected with the middle point of the secondary of the first transformer, as shown, and the three free terminals will then deliver E. M. Fs. differing in phase 120 degrees. If the E. M. F. on each primary be 1,000 volts and on one secondary 100 volts and on the other 87 volts, then the E. M. F. measured between any two secondary terminals will be 100 volts. This three-phase circuit is adapted for operating three-phase motors. In a system of transmission two-phase currents at the generator may be converted into three-phase currents, as shown in Fig. 19, and the windings may be such that the E. M. F. is raised for transmission. The currents are then transmitted by three phases, effecting economy in copper. At the other end of the line a similar arrangement of transformers may be used for converting from the three-phase to the two-phase system. The two-phase currents may then be used for the operation of two-phase motors or the circuits may be independently loaded with lamps, or otherwise. If lamps be placed on the transformer which supplies directly from its two terminals, the transmission is directly from the generator without affecting in any way the other circuit, as the generator terminals are connected directly to the first primaries, and the secondaries of the raising transformer are connected directly to the primaries of the lowering transformer, and the current from this is taken directly to the load. On the other hand, if the other circuit be loaded, the action here will also be on its

Fig 19.

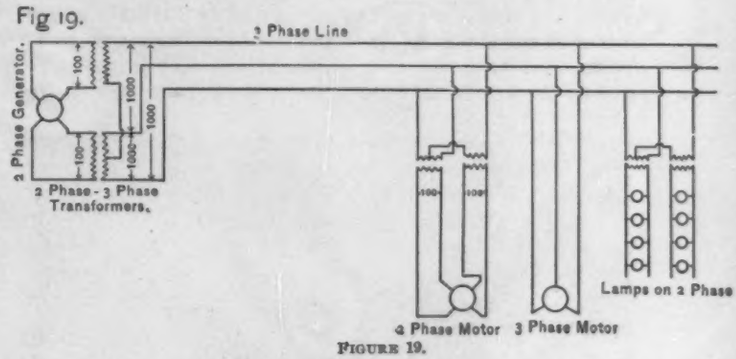


FIGURE 19.

Fig 20.

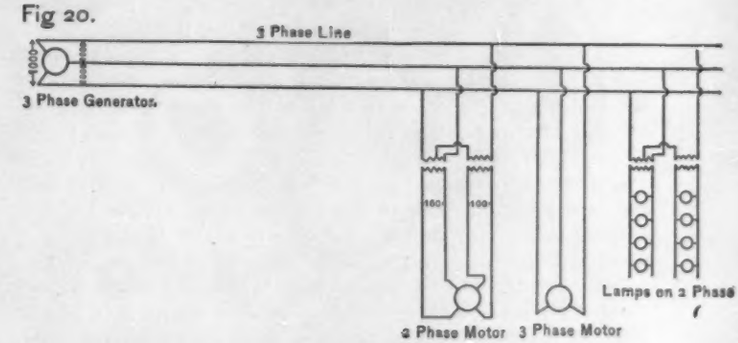


FIGURE 15.

own generator circuit without affecting the first. The current from the raising transformer in this circuit passes to the middle of the secondary of the other transformer, where it divides and flows in parallel through the two parts of the coil and two of the lines. As one-half of the current flows through each part of the secondary coil in opposite directions, the self-induction is completely neutralized and the transformers in this circuit are independent of the operation of the other circuit. It is to be noted that under this condition the line E. M. F. delivered by this transformer is only 87 per cent. of that delivered by the first transformer. The lower E. M. F., however, is

THE BURGDORF-THUN-BAHN THREE-PHASE LOCOMOTIVE.

compensated for by the fact that the current on one side is passed through two of the lines in parallel, thus reducing the resistance of the circuit and compensating for the slightly lower E. M. F.

The effect upon the regulation of the generator when two-phase circuits at the end of a three-phase transmission line are independently loaded is found, both by theory and test, to be the same that prevails when the load is placed directly upon the corresponding circuit of the generator. A modification of this system is found in the arrangement where the three-phase current is produced in the generator and transmitted over three wires to the reducing transformers. These transformers may be arranged as described for producing two phases (Fig. 20). Loads may be placed upon either of the two-phase circuits, and practically the same regulation in the generator will result that would have resulted if the generator itself had been wound for two phases and one of these circuits loaded. In this way it is possible to place lighting load upon a three-phase generator in two instead of three units, and to avoid the bad regulation in the generator due to unequal loading.

A similar arrangement of two transformers may be used for converting three phases of one potential into three phases of another potential. This arrangement is shown in the accompanying Fig. 18.

The efficiency of two transformers arranged for converting from two-phase to three-phase is reduced below that when working independently on ordinary loads by an insignificant amount. If the efficiency in ordinary working is, say, 97.5 per cent., it would be reduced to 97.4 per cent. in converting from one number of phases to the other.

The Tesla polyphase system, in which the largest electrical enterprises are seeking a realization, adapts itself with marvelous facility not only to all branches of electrical industry, but also by the transformation of its phases to the utilization of three phases for gaining the highest economy in transmission, and of two phases for securing the maximum advantages in distribution.

Transportation

THE BURGDORF-THUN-BAHN POLYPHASE RAILWAY.

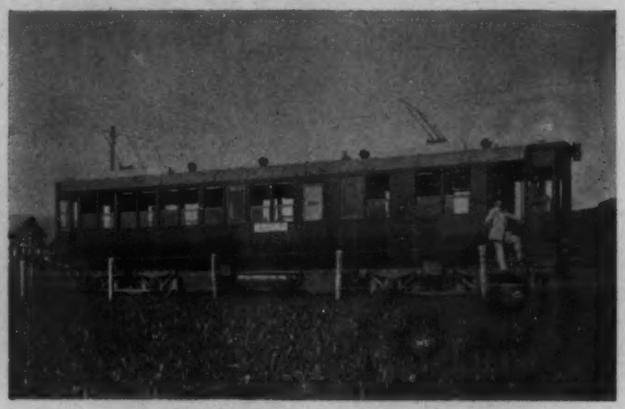
BY ALBERT VAN DER NAILLEN, SR.,
President School of Engineering.

ZERMATT, in Switzerland, is directly connected, through the medium of an electric railway, with the Gornergrat, a most picturesque spot located at an altitude of 10,290 feet in the eternal snow of the Alps — a spot which is believed by all the mountain guides to be the abiding place of that mysterious being called "The Spirit of the Alps," in the existence of which they nourish a most deeply-rooted belief, while holding it in profound and awful reverence.

While looking with much interest at the daring but solid construction of this electric railway on the steep mountain sides and over deep canyons, and noticing the great amount of tourist travel which patronized the road (although the cost is over $3.50 for a ride of only four or five miles), I wondered why it is that in California, where equally charming and interesting spots and scenery exist, we have not the same facilities to offer to the tourists who wish to visit them. We have abundant water power all over the State in all our mountains, enabling cheap transportation, and we might do as is done in Switzerland — let the road lie idle in winter time when the ground is covered with snow and no tourists are "touring."

While thus giving way to reflection, I was approached by a gentleman who, seeing the interest I took in the road, spoke to me and introduced himself as M. Emile Lussy, engineer of and contractor for the building of the road we were inspecting. He told me that this road, like all similar roads in Switzerland, was a paying enterprise, and that the tourists were willing to pay high prices to ride over it, a privilege which they availed themselves of with eagerness, as they supposed that perhaps they would never revisit the scene again. Engineer Luzzy stated that he constructed the mountain road from Viege to Zermatt, the rack and pinion line from Glion Montreux to the rocks of Naye, which ascends to an altitude of 6450 feet in a few miles, and many other mountain lines, all of which pay large dividends.

According to M. Lussy, however, the most interesting electric railway is the recently inaugurated Burgdorf-Thun-Bahn system,



THE BURGDORF-THUN-BAHN PASSENGER CAR.

which is a standard broad-gauge railway line for passengers and heavy freight, and is operated exclusively by polyphase electric locomotives that are the only ones of their kind in Switzerland, if not in Europe. Engineer Lussy invited me to visit the line as his guest and to convince myself personally not only of the splendid working of these polyphase locomotives, but also of the brilliant promises which they hold out to the near future as a means for effecting the economic transportation of heavy materials on steep grades. Having gladly accepted the kind invitation, we started for Burgdorf, where we met by appointment M. Krahenbuhl, the

electrical engineer of the road, a most amiable gentleman, who placed himself entirely at our disposal. Moreover, the electric locomotive here illustrated was turned over to us for a trial and inspection, and concerning which M. Krahenbuhl kindly gave us all information desired.

On the Burgdorf-Thun-Bahn electric railway the passenger traffic is handled by an electric car or cars, while freight is carried in standard Swiss goods cars made up into trains and drawn by

EXTERIOR OF POWER HOUSE AT KANDER, SWITZERLAND.

electric locomotives. The power house, which is illustrated herewith by exterior and interior views, is at Spiez, and the water operating the turbines is taken from the river Kander, which has its source in the lake of Thun high in the mountains. There are four turbines of 900 horsepower each, and these drive through direct-coupling, alternating-current generators, which deliver three-phase current to the step-up transformers at an electromotive force of 4000 volts, whence the three-phase current is delivered to line at 16,000 volts. The length of the road is 35 miles, and the loss on the transmission is six per cent. There are 14 transformers which feed as many different sections of the line with three-phase current at 750 volts, the three sides of the system being afforded in the two overhead trolley wires and the rails.

Neither trolley wheels nor sliding shoes are used, but instead current is taken into the cars through frames of wire placed transverse to the trolley wires overhead, after the manner common to many European systems, as so fully shown in the illustration. The passenger cars take 240 amperes per phase, which is distributed between four motors, thus showing an average consumption of 60 amperes per motor per phase. I am unable to give any information concerning the power factor of the motors, the starting current, torque or regulation of the generators supplying current for the operation of these passenger and freight motors, but will probably be able to do so in the near future in another article to appear in these columns. When exceedingly heavy loads require two driving cars, they together consume 480 amperes on a grade of 25 per cent, with a load of 25 tons. In addition to the driving motors, each car carries a 100-volt induction motor which drives an air compressor for operating Westinghouse air brakes.

In the freight locomotives, the two axles are moved by two connecting rods which are entirely independent of each other, so that if one should happen to break or become disabled the other would continue in service uninterruptedly. In the middle of the shaft receiving and transmitting the power to the connecting rods is a double clutch which permits the adjustment of a wheel and pinion by a single movement, so that the locomotive may run at the rate of either 12 or 24 miles per hour, or at any intermediate speed, on a 25 per cent. grade, with a load of 50 or 100 tons. The locomotive weighs 30 tons, and is equipped with two motors, each having a rated capacity of 150 horsepower. As before stated, there are two trolley wires, but no trolley; the trolley wheel of the form familiar to Americans is mostly suppressed in Switzerland, for the reasons, they say, that it jumps the wire too easily and requires a fine adjustment of wires around curves. Contact is, therefore, secured by the frames shown on top of the cars, and these frames are of sufficient size to always secure positive contact, even in going around curves where the trolley wires are not central over the track.

These Swiss locomotives are of most excellent construction, as well as of the utmost solidity. On noticing the ease with which they perform their heavy work on grades as steep as 25 per cent., I could not help thinking that they are destined to be indicative of the type of electric locomotive with which the future is to be most familiar.

Personal

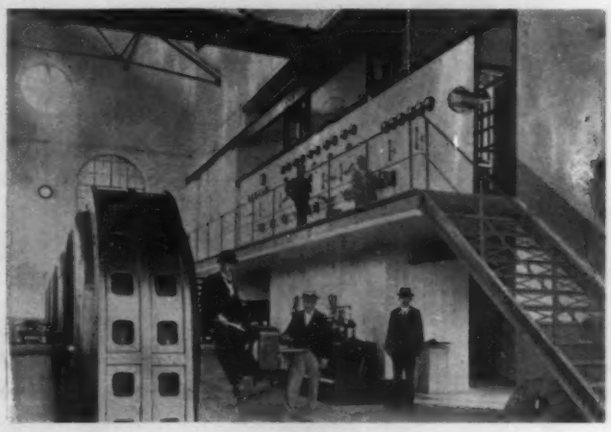
E. M. VAN FRANK has resumed the electrical superintendency of the electric-railway division of the Sutter Street Railway Company, San Francisco, which has acquired the Sutro electric railroad.

MRS. L. E. WILLIAMSON has announced the marriage of her daughter Mary Rhoda to Mr. Thomas Hardin Van Frank, on October 19th, at Rialto, Cal. Mr. Van Frank is well known as the manager of the Brooks-Follis Electric Corporation of San Francisco, and the high esteem in which he is so universally held warrants the JOURNAL in extending to him and his accomplished bride most cordial congratulations, not only in its own behalf, but in behalf of the electrical fraternity of the West.

Steam

STEAM ENGINE EFFICIENCY.

IN a paper recently read before the American Society of Mechanical Engineers by Prof. Thurston, a table is given showing the best economy attained up to the present year with different types of steam engines. The best performance has been from one of the Corliss type using steam at 62 pounds pressure and developing an indicated horsepower on 17.5 pounds of water per hour. A Leavitt pumping compound engine using steam at 135



INTERIOR OF POWER HOUSE AT KANDER, SWITZERLAND.

pounds, developed a horsepower on 12.16 pounds of water per hour, while a high-speed McIntosh & Seymour compound engine has developed an indicated horsepower on 12.76 pounds of steam per hour, the initial pressure being 125 pounds. The best showing for a triple-expansion engine was in the case of a Snow pumping engine using steam at 156 pounds pressure, and developing a horsepower on 11.26 pounds of water per hour. Of quadruple-expansion engines the best record is that of a Hall & Treat engine using steam at 400 pounds pressure and developing a horsepower on 9.67 pounds of steam per hour.

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EDITORIAL.

PHILOSOPHY OF SYNCHRONIZING ALTERNATORS.

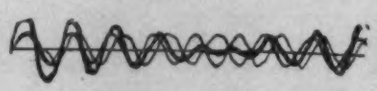
The word "synchronize" implies agreement in points of time; hence, when used in an electrical sense, is equally applicable to both the frequency and the phase relation of alternating-current wave forms. To "synchronize" alternators indicates that they have been brought not only to an equal frequency, but that they have as well been brought to that condition where their phase relations are both identical and simultaneous; that is, that their phases are "in step," meaning thereby, that they give a maximum electromotive force of the same sign at the same instant, and that they continue to be thus in step for an appreciable period of time. Alternators may, therefore, have the same frequency but be out of step; or they may be in step at a given instant, but be out of frequency; but when they have been brought to synchronism, it is understood that they are both in step as to phase relations as well as of equal frequency. The application of these terms in that which follows should now be clear.

When alternators are to be coupled in parallel, they are brought to conditions of equal frequency, of equal phase relations—or in step—and of equal voltage, though the latter is less important than either of the other two conditions. If an unattached single or polyphase alternator have its fields excited and its armature connected up to another similar type of alternator which is being run as a generator, the unattached alternator will exert a very powerful tendency to run with the generator, provided it has been first brought up in step with, and of equal frequency to, the generator. A considerable load may be put upon the motor (for such the unattached alternator becomes) and the two machines will keep in synchronism, for such is their inherent characteristic.

As with direct-current dynamos, the possibility of running alternators in parallel is due to their reversability, or, specifically, to their ability to act as synchronous motors precisely as just described, for if one machine, by reason of mechanical or electrical disturbances, tends to slow up, the other will force current into it, running it as a motor and increasing its speed until it hurries it up into synchronism again. So strong is this effect that if the machines are thrown in parallel when they are in direct opposition of phase, they will right themselves in time, provided they are of the same frequency, or nearly so; but this experiment is sometimes a very trying one, as will be shown.

Messrs. Gardner and Howgrave-Graham,* have compared two alternators which are to be thrown in parallel to two pendulums of slightly different lengths. If these pendulums are started to swing in phase, or in step, they will, after a short time, get out of step until when one is swinging in one direction, the other will swing in the other direction, and, similarly, they will consume the same time to get back into step as was required to get out of step. Two alternators will behave in exactly the same way when they are connected in series and not in synchronism. At one moment they will supply a voltage equal to the algebraic sum of their voltages, and the resultant voltage will be a maximum, and, as time goes on, they will oppose each other, and the algebraic sum will be the arithmetical difference, giving a minimum resultant voltage.

In this figure, the two curves represented by light lines illustrate the curves of two alternators slightly out of synchronism. The heavy line shows the curve that is obtained by taking the algebraic sum of the ordinates of the two light-faced curves, and from these it will be seen that the resultant voltage grows and then dies away. The more nearly the machines are in synchronism the slower the fluctuations will be. This effect is very important, as it is made use of in most synchronizing apparatus.



Assume now, that two machines are up to proper frequency, but are not in step. If they are thrown in parallel when in this condition, a current of greater or less amperage will oscillate between them, which, if their phases are in direct opposition, may be enormous, especially in armatures without iron, in which case the armatures will probably be destroyed. This enormous rush of current will, if the armatures stand the strains caused by it, slow up one of them a little, causing their frequencies to differ, when they will begin a see-sawing which will eventually bring them into synchronism through the motor actions referred to. It will probably take several seconds to accomplish this, during which the voltage of the distribution circuits will be more or less seriously disturbed—so much so that it is sometimes possible for synchronous motors operated therefrom to drop out of step, several such occurrences being sufficient to paralyze the whole system. Alternators having iron-clad armatures, and especially those with big teeth, are of sufficiently high induction to

*Transactions Institution of Electrical Engineers, London, March 22, 1899.

limit the enormous inrush of current caused by synchronizing machines that are seriously out of step; but commercially, alternators which are not in step and not in synchronism—*i. e.:* of equal frequency—are not thrown in parallel unless by accident, for the very cogent reason given.

Regarding frequencies, Steinmitz showed, as early as 1894,* that alternators with a frequency as high as 125 cycles and as low as 25 cycles per second would, when properly designed, work perfectly in parallel; and, moreover, he found that the self-induction of machines within the limits of well-designed alternators has nothing to do with the success of synchronous running, as armatures of low and high self-induction run in parallel with perfect success.

The synchronizing of alternators has now been reduced to a comparatively simple mechanical operation, and even the difficulties which attend the parallel operation of steam-driven, direct-coupled alternators have at last found to be chargeable to the engine rather than to the alternator. Under ordinary conditions the problem of synchronizing slow-speed, direct-coupled, steam-driven generators is one that any steam engine builder can solve by regulating the retarding action of the engine governor, and this retardation need not ordinarily be so great as to seriously affect the speed control. Such synchronizing, when under improper conditions, is apt to be accompanied by periodic cross currents and periodic variations of the cut-offs in both engines, but the cases wherein it becomes very difficult to obtain stable parallel operation will be found to be rare. Of course, all difficulties in synchronizing alternators are greatly reduced by increases of speed, and in water power plants in particular, where high speed and an even angular velocity are combined, the parallel operation of alternators is a process of the utmost reliability.

HIGH VOLTAGE TRANSMISSION LIMITATIONS.

Electric power transmissions for distances approaching 150 miles are projected in several portions of the West and some of these enterprises have passed so far beyond the stages of promotion that they are already looked upon as being all but literal realities. California seems destined to continue to lead the world in electric power transmission, and it already does so in pioneership, in distance of transmission, and in the use of the highest commercially-successful line voltages. But these new transmissions are of such great length that the cost of line construction is bound to compel the making of most strenuous efforts toward the utilization of still higher voltages than any yet found in commercial practice, in view of which the industry must feel grateful to *Cassier's Magazine* for the publication of an article in its last issue on the "Practical Limitations of Electric Power Transmission." In this valued contribution, Dr. Louis Bell gives impartial and conservative discussion of the questions involved, in which the opinion is expressed that the difficulties attending the use of potentials between 50,000 and 60,000 volts are perhaps prohibitive.

Dr. Bell truly points out that during the past half-dozen years a great fund of practical information has accumulated concerning transmission at high voltage, and that within a wide range, engineers are now treading on no uncertain ground. Conservative voltages have been steadily creeping upward, and experiment has grown into standard practice until the art has been revolutionized. The first great step was taken when engineers squarely faced the problem of dealing with alternating currents that demanded that they be treated with respect, and came to a realizing sense that the proper place to insulate a high-tension wire was at its supports. It very soon became evident that when once past pressures which can be handled with impunity, further increases in voltage involved no additional danger and were practically limited only by existing conditions as to insulating the apparatus. Given adequate insulation, the line problem was, is, and ever will be easy.

The upshot of the matter has been that the 1000-volt plants common ten years ago, are now practically obsolete; while for transmission of even a few miles a line pressure of 10,000 volts is generally used, and even local distributions are ordinarily run at or close to 2500 volts. At the present time one may fairly call 10,000 volts the standard working pressure for transmission purposes, and its use has been proven beyond question to be in every way as reliable as if much lower potentials were to be used. As the voltage rises beyond this figure no alarming phenomena appear for some time. The danger of puncturing insulators increases, but this merely makes it necessary to thoroughly test them and to provide a suitable factor of safety. Moreover, raising and lowering transformers are not materially more difficult and expensive to build and insulate. The "striking distance," however, rises noticeably, but its increase is a matter that is not yet troublesome except as it may indicate resonance, to which is frequently due the considerable increase in striking distance often noticed on long lines, which sometimes may become annoying, although seldom serious.

Aside from resonance, little occurs that is noteworthy as the pressure is further raised until it approaches 20,000 volts. At about that point the lines begin to be luminous at night—at first appearing as a hazy bluish film of light at the surface of the wires, with faint brushes at points such as the tips of tie wires. Thus results a static discharge into and through the air along the high-voltage wires. The energy is leaking wherever it gets a chance—from the wires, across the oil in the transformers, and from every point and edge along the line. At 20,000 volts this static leakage amounts to very little as a matter of loss in energy; in fact, it is merely apparent. As the voltage rises above this figure, the discharge becomes more marked until at 40,000 volts a perceptible, though not material, amount of energy is devoted to keeping up this action. It is exactly the same sort of thing that one sees in a darkened room about the wires leading from a

The Electrical World, Vol. XXIII, page 285, March 3, 1894.

powerful Ruhmkorff coil, except that it is on a colossal scale. Add 10,000 or 15,000 volts more to the line and the situation becomes serious, for the energy streams off in amounts rapidly growing graver, and under the terrific strain the air tends to become weaker and weaker as an insulator.

At this point two courses are open: either to increase the distance between the wires or to insulate them. The latter course probabably can not afford permanent relief and the former mitigates the evil but does not altogether cure it. Hence, although one plant is being operated in Utah at 40,000 volts, it seems that this point nears a limitation inherent in air as the medium in which aerial lines work. Between 50,000 and 60,000 volts the case grows very serious, "perhaps prohibitively so," states Dr. Bell, so long as transmission lines are run in air

Operation at these or higher voltages, if at all possible, appears to necessitate a consideration of questions as to whether the lines shall be run underground in expensive cables, or under or above ground in oil tubes. Possibly the latter may be accomplished when some one finds a cheap non-conductor that will hold oil successfully, but even then resonance is to be dreaded. Going underground or into tubes means adding capacity to the system and this means a chance of hitting resonance of lower harmonics, or even the fundamental. Very formidable resonance has been detected on one line having some underground connections, and electrical transmission interests shall hear more of it, although it is worth noting that increased voltage does not necessarily imply increased danger of resonance. In point of voltage, then, trouble must be provided against as 40,000 volts is approached, even in good climate; and, furthermore, the placing of lines underground must be very cautiously done.

Thus is given, almost verbatim, the opinions held by one of the best-known electrical engineers of America on a subject fraught with great concern to transmission interests. Especially is this so to those of California, which is detined to be the scene of action of the highest potentials and the longest distance transmissions of the world. Here the difficulties which are pointed out must be met and overcome, for not many decades will pass before the Sierras will be studded with power houses from the mountain streams of the Southern California Water Company in San Diego, to the McCloud River in Sikiyou, whence transmissions will be run to all cities, towns and industrial centers, and these transmissions will be interlinked as intimately as are those of southern California today. Not only will service interruptions thus be prevented, but the transmissions will be operated at highest possible voltages and over greatest distances within the bounds of commercial limitations. Toward these conclusions all climatic, physical and political conditions trend.

M. Chevalet has muffled the noise of large gas engine exhausts by connecting the exhaust to a small scrubber. With gas engines the scrubber is not supplied with any liquid, but with petroleum engines the escaping products are regularly washed so as to recover the oil and get rid of the smell.

Gas

INDUSTRIAL GAS.—IX.

BY FRANK H. BATES.

THE JUNKER CALORIMETER. Whenever fuel is employed in any quantity, whether gaseous, liquid or solid, an exact knowledge of its calorific power is required in order to decide upon its cost. Likewise the heat energy required for a given work can only be determined by measurement of the fuel when its calorific power is known. For instance, in making a test of a gas engine, a reported consumption of a certain number of cubic feet of city gas, or producer gas, per horsepower-hour, unaccompanied by other data, would be indefinite, since the quality of the gas might vary within a wide range, giving a greater or less consumption per horsepower at different times. It is evident then, that, in order to convey an accurate idea of quantity when

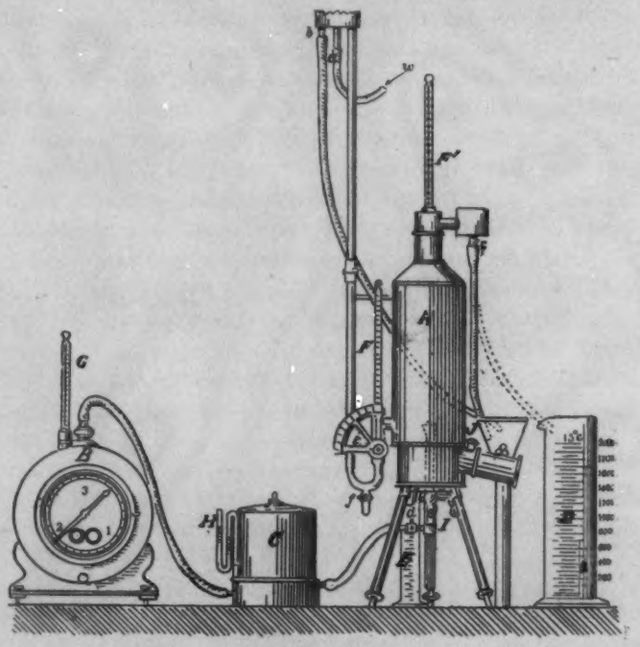


FIGURE 27.

dealing with heat, whatever the source, it is necessary to base all computations upon the number of heat units, when comparative consumptions and costs are readily estimated.

Description of the Junker calorimeter. This instrument is especially suited to the continuous determination of the calorific power of a gas or liquid, since it not only serves to show the heat value of a product at any given time, but additionally, all the fluctuations occurring at various stages of a process.

The apparatus consists of:

A calorimeter proper, designated by A, Figure 27, with a Bunsen burner, I, which projects into the combustion chamber;

A pressure regulator, C, for regulating the pressure of the inflowing gas (thus avoiding the fluctuations in pres-

sure of the gas source), with a small U-tube to indicate the pressure of the gas in inches of water;

An accurate gas meter, B, graduated in litres* and provided with an opening for the insertion, by means of a rubber stopper, of a thermometer for registering the temperature of the outflowing gas. A wet or dry meter may be used according to conditions and preference;

A collecting jar, D, graduated up to 2000 cubic centimeters, for collecting and making measurement of the water used;

A collecting jar, E, graduated up to 100 cubic centimeters, for collecting and making measurement of the water of condensation;

A set of thermometers consisting of three graduated up to 50° C. for the measurement of the temperatures of the air of the room, of the gas at the meter (thermometer G) and of the products of combustion issuing from the calorimeter (thermometer at J); also two standard thermometers (F and F') graduated in tenths of degrees and scaled up to 50° C., for the measurement of the temperatures of the inflowing cold and outflowing heated water of the calorimeter. These thermometers should be provided with adjustable reading glasses;

Rubber stoppers for holding and fitting the thermometers in their respective positions, and rubber tubing for making all connections.

The calorimeter proper consists of a copper vessel, the copper sheeting employed in its construction being as thin as compatible with strength, mounted on adjustable legs, provided with a combustion chamber in which the fuel is burned (if gaseous fuel a regulator insures constant pressure), the products of combustion passing upwards and downwards through the outer compartment of the calorimeter in an opposite direction to the ascending water (which is under a constant head), giving up in transit all the heat resulting from the combustion. The detailed view, Figure 28, makes the construction clear. In the combustion chamber 28, is inserted the Bunsen burner 27, proper adjustment as to the height being made by sliding the carrier 25 along the fixed rod 26 and binding by the set-screw shown. The rod 26 is provided with a flat surface in the rear of the proper position of the burner, so that, on bringing up the set-screw, the burner will be located centrally with reference to the combustion chamber. The heated products of combustion pass to the roof of the chamber and then downward through the network of tubes 30 (shown in both the views A and A'), finally collecting in the cylindrical portion 31, and then passing through the damper 33 of the chimney 32 into the atmosphere. Provision is made for the entrance of water at 1, from where it passes into the small compartment 2 (over which is placed the lid as shown), perforated with small holes which are screened to prevent the passage of foreign matter. Through these perforations of compartment 2 it passes into chamber 3, connected by the piping 6, with a union at 7, to the regulating-cock 9, the pointer of which, together with the graduated arc, is best shown in view A". Sufficient water should be supplied to chamber 3 to maintain a constant overflow from the upper edge into the surrounding chamber 4, from which it may escape by rubber tube connections from the nipple 5. This provides a constant head of water on the regulating-cock 9, insuring the maintenance of the same rate of flow through the instrument when the valve has once been adjusted to suit the requirements of the test.

The course of the water through the calorimeter is as follows: From the regulating-cock 9 it flows around the

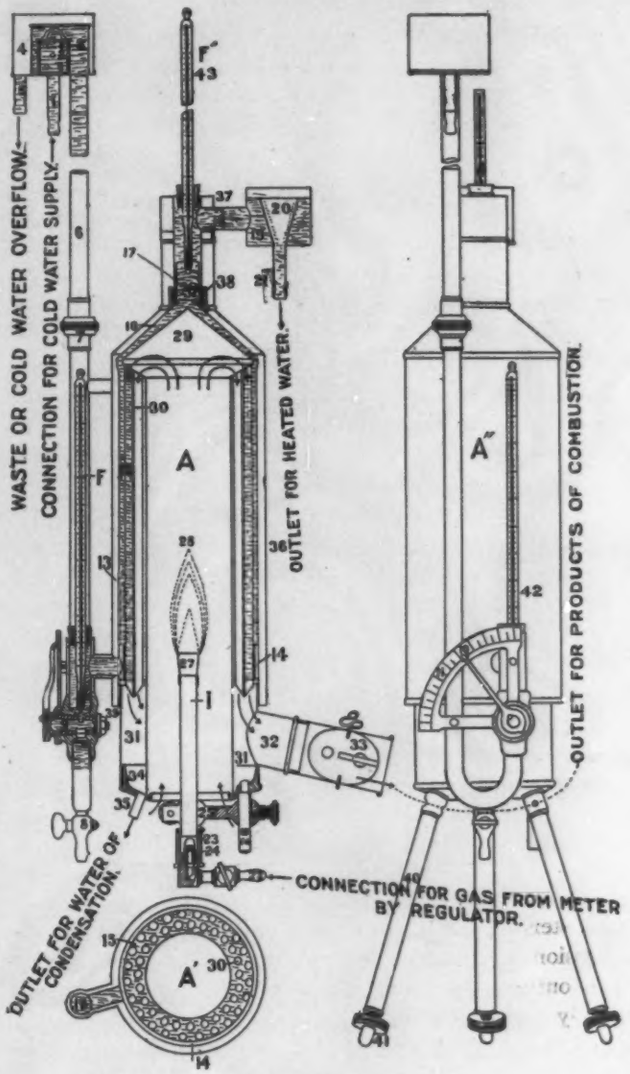


FIGURE 29.

bulb of the thermometer F through the horizontal conduit into the chamber 15 enclosing the tubes, upwards by 16, around the roof of the combustion chamber, through the baffle-plates 17, where it is thoroughly mixed, then around the bulb of the thermometer F' and through the arm 18, to the compartment 19, overflowing into the exit pipe 20. A jacket of air, 13, is placed around the entire body of water to prevent loss of heat by radiation. A small opening at the bottom edge serves to relieve the pressure due to the expansion of the enclosed air, but being the only

*In this description all the measurements are made by the French system; the English system may be substituted, however, using a meter graduated in cubic feet, thermometers in Fahrenheit degrees, and graduates in cubic inches.

one does not give rise to a circulation of the air.* The nipple 35 serves to drain any water resulting from the condensation of the products of combustion.

The pressure regulator is shown in detail in Figure 29. The gas passes from the meter by rubber tubing to nipple A of the regulator, into the lower portion of the central channel B, up by the open valve C, and into the main chamber E. The exit to the burner is by pipe F. Weights are provided with which to vary the pressure, and with a central hole to fit the stem I, over which they are placed, resting on the nut K, made fast to both the shell and stem. The compartment G is partially filled with water to form a seal for the gas. The valve C is actuated by

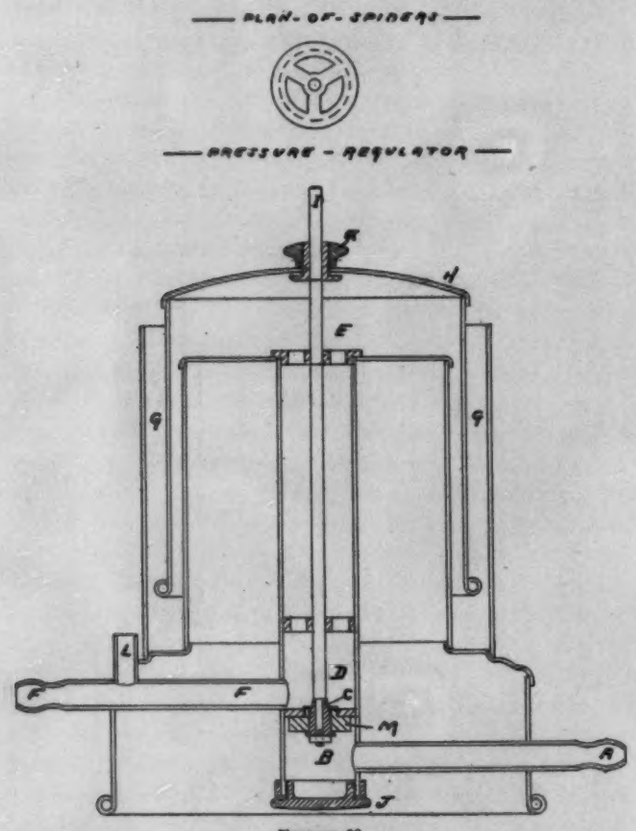


FIGURE 29.

the stem I, which, in rising with the shell, checks the admission of gas until the pressure is slightly reduced by the outflow of gas through pipe F to the burner. With a fairly uniform pressure of gas at the source, the regulator may be adjusted to a nicety, the shell varying its position within a very small range. A regulator is required since the flow of gas to the burner must be maintained at a uniform rate to secure accurate results. The pressure of the gas in the burner is shown by the difference of level of the water in the two limbs of the U-tube (H, Figure 27). If preferable, a dry pressure regulator may be employed, such a one being shown in Figure 30.

The Bunsen burner, with regulating-cock removed, is shown in the sectional view, Figure 31. The cap A on the upper end is detachable, not being required with some gases. It is advisable to employ a small screen to fit in the cap A at about the line B, to prevent the gases taking fire below at the air-valve C, which will sometimes occur with gases requiring a considerable opening of the valve; that is, considerable air for their combustion. This occurring, will put out the light at the top of the burner, making necessary a repitition of the test.

Arrangement of parts. Place the instruments so as to render easy the rapid reading of the thermometers. Level by means of the adjusting screws, both the gas meter and the calorimeter. Make up the connections as shown by Figure 27, and with the thermometers G for measuring the temperature of the gas leaving the meter (when using a wet meter the requisite water should be poured in some little time previous to making the test so that it may acquire the temperature of the room), F and F′ for the temperatures of the cold inflowing and heated outflowing water of the calorimeter, and at J for the exhausting products of combustion, and a thermometer in the room as well (in close proximity to the apparatus) for registering the temperature of the air of the room (giving the temperature of the air entering into combination with the gas in burning).

If possible, have an overhead tank for water of a size suited to the duration of the test, in order to have the temperature of the entering water and the air of the room the same, thus avoiding the necessity for making any correction for air as would probably be the case if the water were taken from an outside source. Keep all temperatures as constant as possible during the tests, and notice that no draft strikes the chimney of the calorimeter. When the tests are of short duration it would be advisable to have one or two assistants in order that simultaneous readings may be taken in quick succession. However taken, all readings should be made at regular intervals in order that a fair average may be obtained.

Have piping from the gas source terminate near the meter with a valve and nipple, connecting the nipple by rubber tubing to the inlet of the meter.

Connect the water inlet *a*, by tubing to a similar pipe with valve and nipple, from the water supply.

Attach a piece of tubing to the cold-water overflow *b*, to reach handily to the drain, which should be fitted with a glass funnel to show the outflowing water from the position of the operator. A drain should be provided close to the calorimeter.

Attach a piece of tubing to the heated water outlet *c*, of a length such as will permit of its end being placed alternately in the drain and graduate D, which should be placed close by, with the graduations outward, that they may be noted.

The small graduate E is placed beneath the nipple *d*, for the collection of the water of condensation.

The burner I is inserted within the combustion chamber about 12 centimeters (4.7 inches), the exact distance depending on conditions.

*The only means by which loss of heat could take place would be by either conduction or convection through the air to the outer surface from which to radiate. Conduction will take place only to a slight degree, air being a very poor carrier; and convection is out of the question, there being no circulation. Furthermore, the outer surface is highly polished, reducing radiation to a minimum. We may therefore consider, for all practical purposes, that no loss of heat takes place.

The drip, or bleeder, *f*, provides for the drainage of the water column and is, consequently, only used when taking the instrument down, being closed during operation.

The flue of the calorimeter chimney is opened to suit prevailing conditions, generally not requiring any particular adjustment.

Operation. 1. Test the calorimeter for leakage by opening the water-supply valve and regulating-cock *e*, causing the water to shortly issue from the outlet *c*.

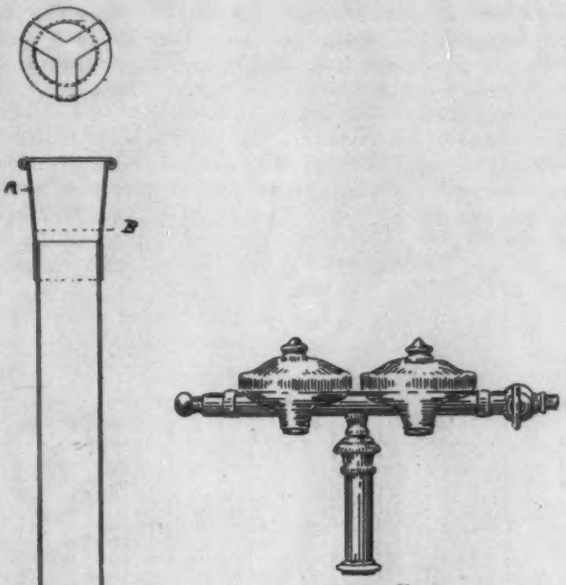


FIGURE 30.

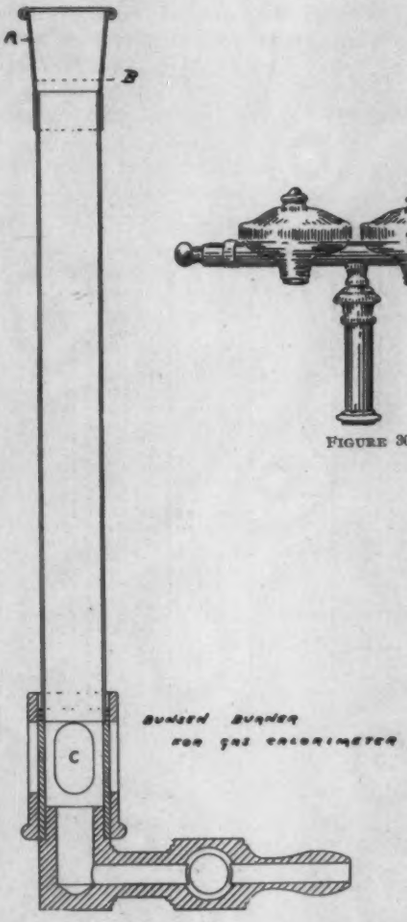


FIGURE 31.

After a brief wait, if no water drips from the drain *d*, one is certain that there is no leakage.

2. By means of the regulating-cock *e*, adjust the flow of water so as to cause it to issue from *c* at a rate that will about fill the large graduate (2000 cubic centimeters capacity) in five minutes.

3. Adjust the valve on the water supply so as to admit through the cold-water inlet *a* sufficient to cause a slight but constant overflow from the cold-water overflow *b*, seen in the glass funnel into which the connecting tube drains, thus insuring a constant head on the regulating-cock *e*.

4. Pour enough water in by the top of the regulator C to form a water seal when the cover is at its highest position. Also pour a little water in the U-column H.

5. Adjust the valve on gas supply to admit a small flow to the meter, and then adjust the Bunsen burner regulating-cock to give a flame such as will maintain a difference in the temperatures of the incoming and outgoing water of about 10° C. The precaution must be taken to light the burner outside the calorimeter. The pressure regulator should be weighted to maintain the proper pressure of gas in the burner.

We now have the following order of operation:

Gas is passing from the source of supply through the meter, around the bulb of the thermometer G (Figure 27), by the meter outlet through the rubber tube connection to the regulator C (the gas pressure being indicated in inches of water on the limbs of the U-tube H), through the regulator outlet by rubber tube connection to the Bunsen burner I, through the burner valve to the tip where it is burned in the combustion chamber of the calorimeter A. The products of combustion pass upwards to the roof and then downwards through the tubes, around which the cold water is ascending, giving up to the latter in the passage all the heat generated by the combustion, then issuing from the outlet or chimney immediately after having passed the bulb of the thermometer J. Water is passing from the source of supply to the cold-water inlet *a* in sufficient quantity to give a constant head at the regulating-cock *e*, from which it passes around the bulb of the thermometer F just previous to entering the calorimeter, through which it ascends, absorbing in the passage the heat of the down-flowing products of combustion. Thoroughly mixed by the baffle-plates in the upper portion of the calorimeter, it passes around the bulb of the thermometer F' and immediately through the heated water outlet *c* to the drain or graduate.

Special hints. Caution should be exercised to prevent the water in the calorimeter becoming too hot, as it would expand the mercury in the thermometers to such an extent as to break them. When the nature of the gas does readily admit of securing the proper difference in the temperatures of the ingoing and outgoing water by a regulation of the flow of gas, a slight adjustment of rate of the water flow will effect the desired result.

Always light the Bunsen burner outside the calorimeter, and only insert in the combustion chamber after allowing a sufficient lapse of time to permit of any gases collected therein to pass out, otherwise a severe explosion may result.

Regarding the adjustment of the air-valve on the Bunsen burner, see that a sufficient quantity of air is admitted to render the combustion as smokeless (flame showing as little carbon as possible) or as complete as possible. With producer gas or gas of low calorific power, no air whatever need be admitted to the burner, whereas with gas of high calorific power, as coal gas, considerable is required.

The entire consumption of water need not exceed three liters per minute.

The consumption of gas will be in accordance with its calorific power, making it impossible to direct the use of

a certain flow of gas or certain length of flame at the burner. The extreme capacity of the calorimeter is 2500 calories per hour. It is advisable to operate with a rate such as will give an absorption of about 1200 calories per hour.

(Continuation in next number.)

THE SUN AS A SOURCE OF ENERGY.*

BY DR. W. BORCHERS.

ALL natural energy which man possesses in the present condition of the earth's crust and which puts and keeps in motion the action of machinery, mechanisms, and living organisms, is derived directly or indirectly from the radiating energy of the sun. The various forms of such energy may be converted more or less easily one into the other, and among these forms are distinguished (1) radiating energy, visible light and invisible rays ascertainable by their chemical or electrical effects; (2) heat; (3) mechanical energy; (4) electrical energy; (5) chemical energy. The most fugutive of these is radiating energy.

Note what becomes of this radiating energy upon striking the earth. One part of it is converted at once into heat in which form it penetrates into the earth at a moderate depth, doing work which is partly mechanical, partly chemical. The mechanical work consists chiefly in evaporating and lifting water. If there be assumed a mean rainfall of one metre (39.37 inches) and the height of the clouds at 3000 metres (9842.5 feet), the work done by the sun equals 661,560,000,000 horsepower per second. Only a vanishingly small part of this energy can be utilized by man, but today the attempt is made to sieze it wherever it can possibly be caught.

Not less noticeable a part of the sun's energy is directly or indirectly converted into chemical energy. Through the reaction taking place in the bodies of plants, and simply expressed by the formula $6CO_2 + 5H_2O = C_6H_{10}O_5 + 6C_2$, are obtained wood and other plant fibers, starches and other similar substances suitable for creating heat. It has been proved that about one kilogramme (2.2 pounds) of wood can be made to grow annually on one square metre of suitable soil. From one square kilometre of wood or farm land may be obtained 1000 tons of vegetable matter with a thermal value of 4000 calories per kilogram (7108 British thermal units per pound), which is equivalent to about 700 horsepower delivered continuously. Assuming but a very small proportion of the entire terrestrial surface of 136,038,872 square

*From "Electrolytic Processes in Industrial Operations," in *The Engineering Magazine*, Vol. XVIII, page 389, December, 1899; abstract.

TEMPERATURE CONVERSION TABLES. (from Kent.)

IV.—CENTIGRADE TO FAHRENHEIT.

C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C	F.
−40	−40.	26	78.8	92	197.6	158	316.4	294	425.2	290	554	950	1742
−39	−38.2	27	80.6	93	199.4	160	318.2	295	437.	300	572	960	1760
−38	−36.4	28	82.4	94	201.2	160	320.	296	438.8	310	590	970	1778
−37	−34.6	29	84.2	95	203.	161	321.8	297	440.6	320	608	980	1796
−36	−32.8	30	86.	96	204.8	162	323.6	298	442.4	330	626	990	1814
−35	−31.	31	87.8	97	206.6	163	325.4	299	444.2	340	644	1000	1832
−34	−29.2	32	89.6	98	208.4	164	327.2	300	446.	350	662	1010	1850
−33	−27.4	33	91.4	99	210.2	165	329.	231	447.8	360	680	1020	1868
−32	−25.6	34	93.2	100	212.	166	330.8	232	449.6	370	698	1030	1886
−31	−23.8	35	95.	101	213.8	167	332.6	233	451.4	380	716	1040	1904
−30	−22	36	96.8	102	215.6	168	334.4	234	453.2	390	734	1050	1922
−29	−20.2	37	98.6	103	217.4	169	336.2	235	455	400	752	1060	1940
−28	−18.4	38	100.4	104	219.2	170	338.	236	456.8	410	770	1070	1958
−27	−16.6	39	102.2	105	221.	171	339.8	237	458.6	420	788	1080	1976
−26	−14.8	40	104.	106	222.8	172	341.6	238	460.4	430	806	1090	1994
−25	−13.	41	105.8	107	224.6	173	343.4	239	462.2	440	824	1100	2012
−24	−11.2	42	107.6	108	226.4	174	345.2	240	464.	450	842	1110	2030
−23	−9.4	43	109.4	109	228.2	175	347.	241	465.8	460	860	1120	2048
−22	−7.6	44	111.2	110	230	176	348.8	242	467.6	470	878	1130	2066
−21	−5.8	45	113.	111	231.8	177	350.6	243	469.4	480	896	1140	2084
−20	−4.	46	114.8	112	233.6	178	352.4	244	471.2	490	914	1150	2102
−19	−2.2	47	116.6	113	235.4	179	354.2	245	473	500	932	1160	2120
−18	−0.4	48	118.4	114	237.2	180	356.	246	474.8	510	950	1170	2138
−17	+1.4	49	120.2	115	239	181	357.8	247	476.6	520	968	1180	2156
−16	3.2	50	122.	116	240.8	182	359.6	248	478.4	530	986	1190	2174
−15	5.	51	123.8	117	242.6	183	361.4	249	480.2	540	1004	1200	2192
−14	6.8	52	125.6	118	244.4	184	363.2	250	482.	550	1022	1210	2210
−13	8.6	53	127.4	119	246.2	185	365.	251	483.8	560	1040	1220	2228
−12	10.4	54	129.2	120	248.	186	366.8	252	485.6	570	1058	1230	2246
−11	12.2	55	131.	121	249.8	187	368.6	253	487.4	580	1076	1240	2264
−10	14.	56	132.8	122	251.6	188	370.4	254	489.2	590	1094	1250	2282
−9	15.8	57	134.6	123	253.4	189	372.2	255	491.	600	1112	1260	2300
−8	17.6	58	136.4	124	255.2	190	374.	256	492.8	610	1130	1270	2318
−7	19.4	59	138.2	125	257.	191	375.8	257	494.6	620	1148	1280	2336
−6	21.2	60	140.	126	258.8	192	377.6	258	496.4	630	1166	1290	2354
−5	23.	61	141.8	127	260.6	193	379.4	259	498.2	640	1184	1300	2372
−4	24.8	62	143.6	128	262.4	194	381.2	260	500.	650	1202	1310	2390
−3	26.6	63	145.4	129	264.2	195	383.	261	501.8	660	1220	1320	2408
−2	28.4	64	147.2	130	266.	196	384.8	262	503.6	670	1238	1330	2426
−1	30.2	65	149.	131	267.8	197	386.6	263	505.4	680	1256	1340	2444
0	32.	66	150.8	132	269.6	198	388.4	264	507.2	690	1274	1350	2462
+1	33.8	67	152.6	133	271.4	199	390.2	265	509.	700	1292	1360	2480
2	35.6	68	154.4	134	273.2	200	392.	266	510.8	710	1310	1370	2498
3	37.4	69	156.2	135	275.	201	393.8	267	512.6	720	1328	1380	2516
4	39.2	70	158.	136	276.8	202	395.6	268	514.4	730	1346	1390	2534
5	41.	71	159.8	137	278.6	203	397.4	269	516.2	740	1364	1400	2552
6	42.8	72	161.6	138	280.4	204	399.2	270	518.	750	1382	1410	2570
7	44.6	73	163.4	139	282.2	205	401.	271	519.8	760	1400	1420	2588
8	46.4	74	165.2	140	284.	206	402.8	272	521.6	770	1418	1430	2606
9	48.2	75	167.	141	285.8	207	404.6	273	523.4	780	1436	1440	2624
10	50.	76	168.8	142	287.6	208	406.4	274	525.2	790	1454	1450	2642
11	51.8	77	170.6	143	289.4	209	408.2	275	527.	800	1472	1460	2660
12	53.6	78	172.4	144	291.2	210	410.	276	528.8	810	1490	1470	2678
13	55.4	79	174.2	145	293.	211	411.8	277	530.6	820	1508	1480	2696
14	57.2	80	176.	146	294.8	212	413.6	278	532.4	830	1526	1490	2714
15	59.	81	177.8	147	296.6	213	415.4	279	534.2	840	1544	1500	2732
16	60.8	82	179.6	148	298.4	214	417.2	280	536.	850	1562	1510	2750
17	62.6	83	181.4	149	300.2	215	419.	281	537.8	860	1580	1520	2768
18	64.4	84	183.2	150	302.	216	420.8	282	539.6	870	1598	1530	2786
19	66.2	85	185.	151	303.8	217	422.6	283	541.4	880	1616	1540	2804
20	68.	86	186.8	152	305.6	218	424.4	284	543.2	890	1634	1550	2822
21	69.8	87	188.6	153	307.4	219	426.2	285	545.	900	1652	1600	2912
22	71.6	88	190.4	154	309.2	220	428.	286	546.8	910	1670	1650	3002
23	73.4	89	192.2	155	311.	221	429.8	287	548.6	920	1688	1700	3092
24	75.2	90	194.	156	312.8	222	431.6	288	550.4	930	1706	1750	3182
25	77.	91	195.8	157	314.6	223	433.4	289	552.2	940	1724	1800	3272

V.—FAHRENHEIT TO CENTIGRADE.

F.	C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C.
−40	−40.	26	−3.3	92	33.3	158	70.	224	106.7	290	143.3	350	182.2
−39	−39.4	27	−2.8	93	33.9	159	70.6	225	107.2	291	143.9	370	187.8
−38	−38.9	28	−2.2	94	34.4	160	71.1	226	107.8	292	144.4	380	193.3
−37	−38.3	29	−1.7	95	35.	161	71.7	227	108.3	293	145.	390	198.9
−36	−37.8	30	−1.1	96	35.6	162	72.2	228	108.9	294	145.6	400	204.4
−35	−37.2	31	−0.6	97	36.1	163	72.8	229	109.4	295	146.1	410	210.
−34	−36.7	32	0.	98	36.7	164	73.3	230	110.	296	146.7	420	215.6
−33	−36.1	33	+0.6	99	37.2	165	73.9	231	110.6	297	147.2	430	221.1
−32	−35.6	34	1.1	100	37.8	166	74.4	232	111.1	298	147.8	440	226.7
−31	−35.	35	1.7	101	38.3	167	75.	233	111.7	299	148.3	450	232.2
−30	−34.4	36	2.2	102	38.9	168	75.6	234	112.2	300	148.9	460	237.8
−29	−33.9	37	2.8	103	39.4	169	76.1	235	112.8	301	149.4	470	243.3
−28	−33.3	38	3.3	104	40.	170	76.7	236	113.3	302	150.	480	248.9
−27	−32.8	39	3.9	105	40.6	171	77.2	237	113.9	303	150.6	490	254.4
−26	−32.2	40	4.4	106	41.1	172	77.8	238	114.4	304	151.1	500	260.
−25	−31.7	41	5.	107	41.7	173	78.3	239	115.	305	151.7	510	265.6
−24	−31.1	42	5.6	108	42.2	174	78.9	240	115.6	306	152.2	520	271.1
−23	−30.6	43	6.1	109	42.8	175	79.4	241	116.1	307	152.8	530	276.7
−22	−30.	44	6.7	110	43.3	176	80.	242	116.7	308	153.3	540	282.2
−21	−29.4	45	7.2	111	43.9	177	80.6	243	117.2	309	153.9	550	287.8
−20	−28.9	46	7.8	112	44.4	178	81.1	244	117.8	310	154.4	560	293.3
−19	−28.3	47	8.3	113	45.	179	81.7	245	118.3	311	155.	570	298.9
−18	−27.8	48	8.9	114	45.6	180	82.2	246	118.9	312	155.6	580	304.4
−17	−27.2	49	9.4	115	46.1	181	82.8	247	119.4	313	156.1	590	310.
−16	−26.7	50	10.	116	46.7	182	83.3	248	120.	314	156.7	600	315.6
−15	−26.1	51	10.6	117	47.2	183	83.9	249	120.6	315	157.2	610	321.1
−14	−25.6	52	11.1	118	47.8	184	84.4	250	121.1	316	157.8	620	326.7
−13	−25.	53	11.7	119	48.3	185	85.	251	121.7	317	158.3	630	332.2
−12	−24.4	54	12.2	120	48.9	186	85.6	252	122.2	318	158.9	640	337.8
−11	−23.9	55	12.8	121	49.4	187	86.1	253	122.8	319	159.4	650	343.3
−10	−23.3	56	13.3	122	50.	188	86.7	254	123.3	320	160.	660	348.9
−9	−22.8	57	13.9	123	50.6	189	87.2	255	123.9	321	160.6	670	354.4
−8	−22.2	58	14.4	124	51.1	190	87.8	256	124.4	322	161.1	680	360.
−7	−21.7	59	15.	125	51.7	191	88.3	257	125.	323	161.7	690	365.6
−6	−21.1	60	15.6	126	52.2	192	88.9	258	125.6	324	162.2	700	371.1
−5	−20.6	61	16.1	127	52.8	193	89.4	259	126.1	325	162.8	710	376.7
−4	−20.	62	16.7	128	53.3	194	90.	260	126.7	326	163.3	720	382.2
−3	−19.4	63	17.2	129	53.9	195	90.6	261	127.2	327	163.9	730	387.8
−2	−18.9	64	17.8	130	54.4	196	91.1	262	127.8	328	164.4	740	393.3
−1	−18.3	65	18.3	131	55.	197	91.7	263	128.3	329	165.	750	398.9
0	−17.8	66	18.9	132	55.6	198	92.2	264	128.9	330	165.6	760	404.4
+1	17.2	67	19.4	133	56.1	199	92.8	265	129.4	331	166.1	770	410.
2	16.7	68	20.	134	56.7	200	93.3	266	130.	332	166.7	780	415.6
3	16.1	69	20.6	135	57.2	201	93.9	267	130.6	333	167.2	790	421.1
4	15.6	70	21.1	136	57.8	202	94.4	268	131.1	334	167.8	800	426.7
5	15.	71	21.7	137	58.3	203	95.	269	131.7	335	168.3	810	432.2
6	14.4	72	22.2	138	58.9	204	95.6	270	132.2	336	168.9	820	437.8
7	13.9	73	22.8	139	59.4	205	96.1	271	132.8	337	169.4	830	443.3
8	13.3	74	23.3	140	60.	206	96.7	272	133.3	338	170.	840	448.9
9	12.8	75	23.9	141	60.6	207	97.2	273	133.9	339	170.6	850	454.4
10	12.2	76	24.4	142	61.1	208	97.8	274	134.4	340	171.1	860	460.
11	11.7	77	25.	143	61.7	209	98.3	275	135.	341	171.7	870	465.6
12	11.1	78	25.6	144	62.2	210	98.9	276	135.6	342	172.2	880	471.1
13	10.6	79	26.1	145	62.8	211	99.4	277	136.1	343	172.8	890	476.7
14	10.	80	26.7	146	63.3	212	100.	278	136.7	344	173.3	900	482.2
15	9.4	81	27.2	147	63.9	213	100.6	279	137.2	345	173.9	910	487.8
16	8.9	82	27.8	148	64.4	214	101.1	280	137.8	346	174.4	920	493.3
17	8.3	83	28.3	149	65.	215	101.7	281	138.3	347	175.	930	498.9
18	7.8	84	28.9	150	65.6	216	102.2	282	138.9	348	175.6	940	504.4
19	7.2	85	29.4	151	66.1	217	102.8	283	139.4	349	176.1	950	510.
20	6.7	86	30.	152	66.7	218	103.3	284	140.	350	176.7	960	515.6
21	6.1	87	30.6	153	67.2	219	103.9	285	140.6	351	177.2	970	521.1
22	−5.6	88	31.1	154	67.8	220	104.4	286	141.1	352	177.8	980	526.7
23	−5.	89	31.7	155	68.3	221	105.	287	141.7	353	178.3	990	532.2
24	−4.4	90	32.2	156	68.9	222	105.6	288	142.2	354	178.9	1000	537.8
25	−3.9	91	32.8	157	69.4	223	106.1	289	142.8	355	179.4	1010	543.3

kilometres to be capable of supporting vegetation, the amount of power so converted from the radiating energy of the sun would also reach an imposing figure. For many thousands of years this vegetable growth with its incident mouldering and decaying processes, has been in operation as a radiating-energy accumulator, gathering into the earth's crust stores of energy in the form of peat, lignite, coal, etc.

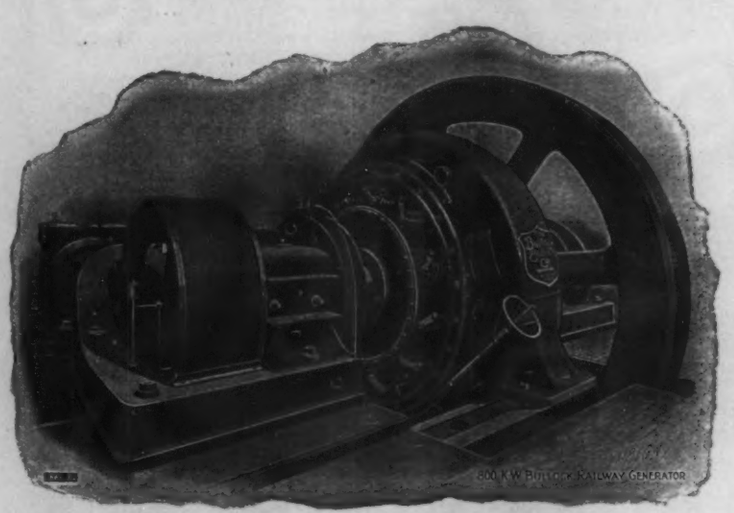
Up to the present time we have consumed principally the last-named stores, and that in no economical manner, using the most of the best, because considerations of transportation required the greatest possible storage of energy per unit of weight. The turf and coal beds of lower calorific value have hardly been noticed, and large industrial centers have been developed upon richer coal basins. Only within the last few decades have the favorable opportunities offered by nature to draw upon cheap and available power been utilized, and these have been mainly water powers. A point here or there, situated near the great thoroughfares of commerce, has already admitted of a better exploitation of a water power, but on the whole, notwithstanding the best intentions of an active spirit of enterprise, there has been a lack of effective work.

Industrial

In responding to advertisements in this publication kindly mention "The Journal of Electricity, Power and Gas."

BULLOCK ENGINE TYPE GENERATORS.

PROMINENT as marking the entry of a new concern into the field occupied by the comparatively few builders of direct connected direct current generators is the new machine recently brought out by the Bullock Electric Manufacturing Co., of Cincinnati, O. Among the more important features embodied in this new machine may be mentioned the scheme for oscillating the brush holder mechanism in a direction parallel with the shaft. The movement is very slow and results in constantly changing the line of travel over the commutator face and thus removes all tendency to cut or groove the latter. The action is the same as secured by the end play of an armature in a belted generator or that produced by the electro magnetic device used at the end of shaft on rotary



transformers, and which is recognized by engineers as a means of greatly prolonging the life of the commutator.

The pole pieces and coils may be removed without disturbing the yoke or armature, and with two of them removed, it is possible to remove one or more armature coils should repairs be necessary.

The armature coils are made of continuous bars of copper without joints between the commutator connections which materially adds to the life of the machine. These coils are all thoroughly insulated, pressed and baked before being placed on the core, no additional core insulation being necessary. All armatures are thoroughly ventilated by slots perpendicular to the shaft through which the air rushes when the machine is in operation. A liberal rating permits of constant operation at full load with low temperature rise. One of the 800 K. W. machines has been sold to the Oakland Rapid Transit Company, of Oakland, Cal., and is shown in the engraving. This machine operates at a speed of 80 R. P. M., and at this speed develops 550 volts at no load.

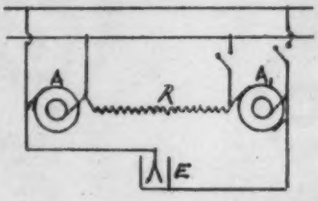
It is over-compounded for a rise of 50 volts at full load, making the full load voltage 600.

Obituary

CAPT. J. F. LUTTRELL died at Marysville, Cal., on November 4th, from pneumonia, after a very brief illness. At the time of his death he was general manager for the Yuba Power Company, with headquarters at Marysville, and though not generally known in electrical or engineering circles, those who were so fortunate as to have made his acquaintance will always cherish his memory as being that of one who was possessed of all that goes to make man loved and esteemed by his fellow men.

AYRTON'S ELECTROSTATIC SYNCHRONIZER.

SYNCHRONIZING transformers are unnecessary when the Ayrton electrostatic synchronizer is used. The system is very simple. R is a resistance, such as a thin line made by a lead pencil on a piece of slate; E is any dead-beat electrostatic voltmeter, such as a gold leaf electroscope which may be made with leaves even eighteen inches long, so as to be seen all over the station; and A and A_1 are the two alternators to be thrown in parallel on the 'bus bars shown. The moment for switching-in is when the leaves stay closed or are together for some appreciable time.



Prof. Ayrton claims that this method is more dead-beat than a lamp, that it is cheaper than the ordinary methods, that it may be of any size, that it requires neither calibration or scale, and that it is perfectly and absolutely safe.

PLOTTING MAGNETIC FIELDS.*

BY W. W. GRIFFITH.

THERE are three different ways of experimentally plotting the lines of force of a magnetic field. One is Faraday's method of iron filings; another consists of drawing elements of the curves from the orientation of a small magnetic needle passed along then; a third consists of observing the motion of a floating needle. These three methods give different results and for obvious reasons. A small particle of iron is influenced by its neighboring particles as well as by the magnet. Being a magnet by induction, its magnetism decreases rapidly as the distance increases, and, therefore, the earth's field has less disturbing effect on the filing-marked lines than on the lines plotted by means of a permanently magnetized needle. The third method is most closely in accord with the definition of a line of force as the line along which an elementary pole would move; but that pole is supposed to be free from inertia, which would otherwise tend to make the needle move on in a straight line.

*Abstract from *Terrestrial Magnetism*, September, 1899.

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ABNER DOBLE COMPANY, Fremont and Howard streets, San Francisco.
Iron, Steel, Mining and Milling Supplies, Rock Drills, Air Compressors, Crocker-Wheeler Dynamos and Motors, Cutler-Hammer Electrical Apparatus, the Doble Ellipsoidal Water Wheels.....See page viii

BABCOCK & WILCOX CO., 29 Cortlandt street, New York, and Pacific Coast office, 32 First street, San Francisco.
Babcock & Wilcox Water Tube Steam Boilers.....See page iii

BATES, FRANK H., 933 Market street, San Francisco.
Chemical and Gas Engineer.....See page iii

BENJAMIN, EDWARD H., 331 Pine street, San Francisco.
Mining Engineer.....See page iii

BROOKS-FOLLIS ELECTRIC CORPORATION, 523-525 Mission street, San Francisco.
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Consulting, Supervising and Constructing Mechanical and Hydraulic Engineers.....See page iii

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The Knight Water Wheel, Hydraulic and Cornish Pumps, Mining Cars and Cages, Horizontal and Vertical Engines, Automatic Water Power Attachments, Hoists, Quartz Mills, Sheet-iron Pipe, Water and Ore Buckets, General Foundry and Machine Shops.....See page v

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LOCKE, FRED M., Victor, N. Y.
Locke Glass and Porcelain Insulators, Steel Pins, Break Arms, Side Brackets, Ridge Irons and Line Materials for all services....See page vii

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Consulting, Supervising and Constructing Electrical Engineer..See page iii

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Pacific Coast Agents for Babcock & Wilcox Boilers, McIntosh & Seymour Engines, Hamilton-Corliss Engines, N. Y. Safety Automatic Engines, Green's Economisers, Wheeler Condensers, Barnard-Wheeler Cooling Towers, Hoppes' Live Steam Purifiers, Goubert Feed Water Heaters, Stratton Steam Separators, Snow Steam Pumps, Quimby Screw Pumps, Edmiston Feed Water Filters, Geipel Steam Traps, Spencer Damper Regulators, Hyatt Roller Bearings, Chapman Valves, Holly Gravity Feedwater Return System.....See page iii

MARTIN, JOHN, 300 California street, San Francisco.
Pacific Coast Agent Locke Insulators and Line Materials, Pittsburg Reduction Co.'s Aluminum Wires for Electrical Circuits, Stanley Electric Manufacturing Co.'s "S. K. C." system for electrical transmission and distribution.....See pages vi, vii, viii

NEW YORK INSULATED WIRE CO., THE, 15-19 Cortlandt street, New York; John R. Cole, Sales Agent, 83 Flood Building, San Francisco.
Sole Manufacturers of Grimshaw, Raven and Competition Rubber covered Wires, Tapes and Splicing Compounds, Large Cables and Leaded Cables of any voltage.....See page iv

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Sole Manufacturers of Okonite Wires, Cables and Tape, Manson Tape, Candee Weatherproof Wires.....See page i

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Manufacturers and Renewers of Incandescent Lamps of all voltages and in all candle powers.....See page iii

PARAFFINE PAINT CO., 116 Battery street, San Francisco.
Manufacturers of P. & B. Armature and Field Coil Varnish, Electrical Compound, Insulating Tape, Roofing, Building Paper and Paint..See page vii

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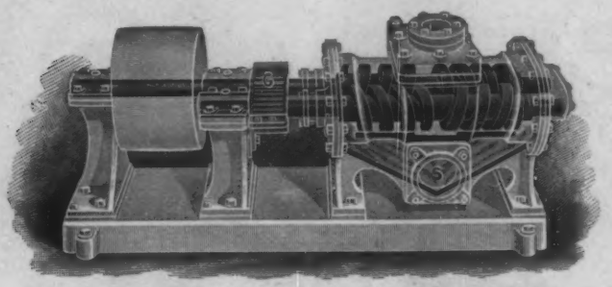

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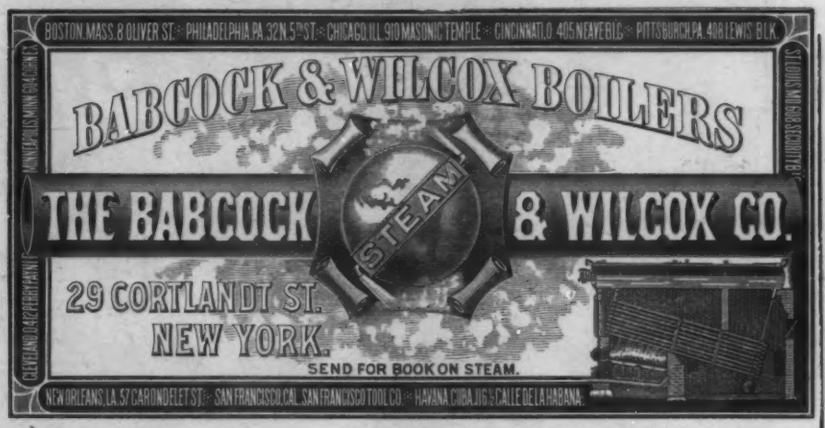
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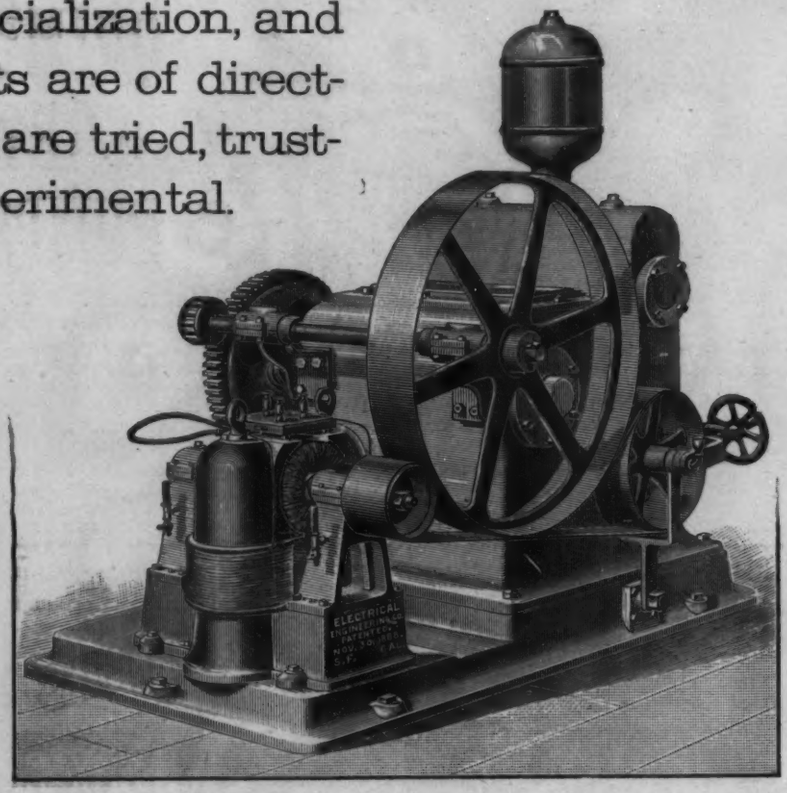

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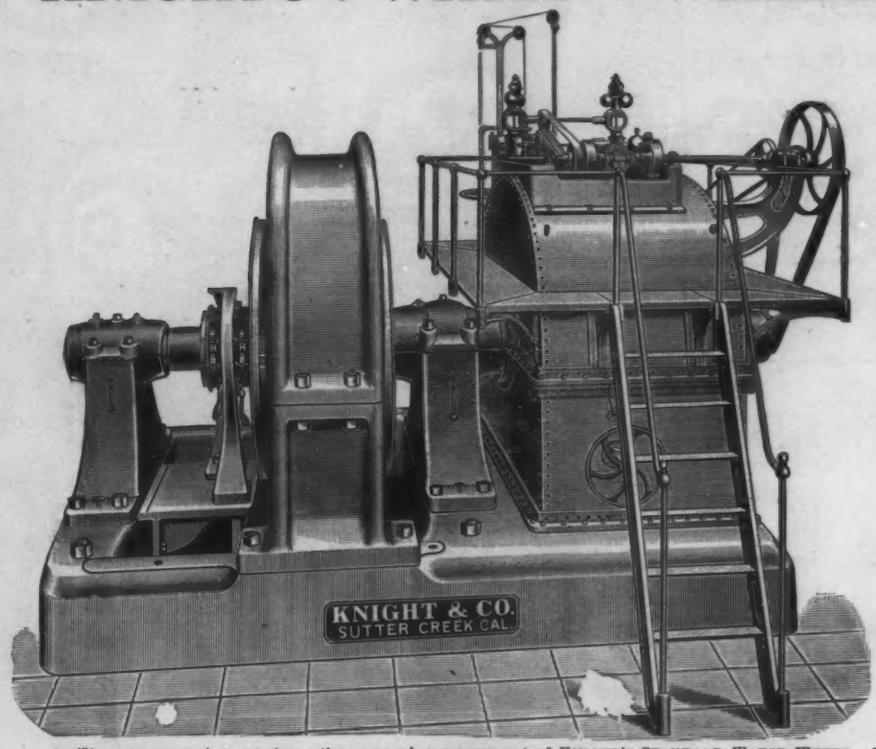

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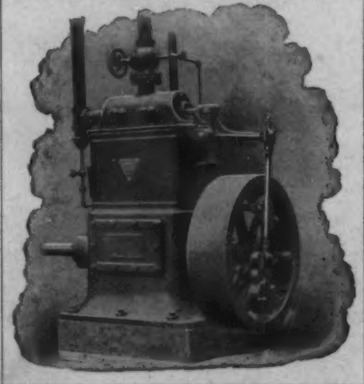

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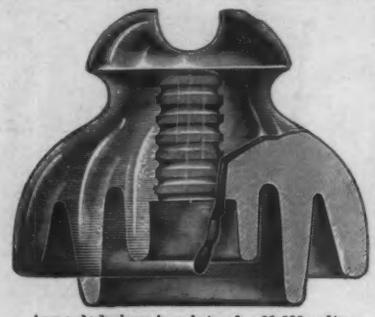

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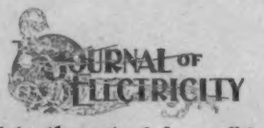

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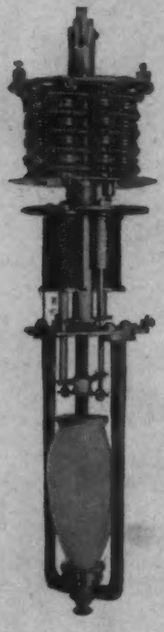

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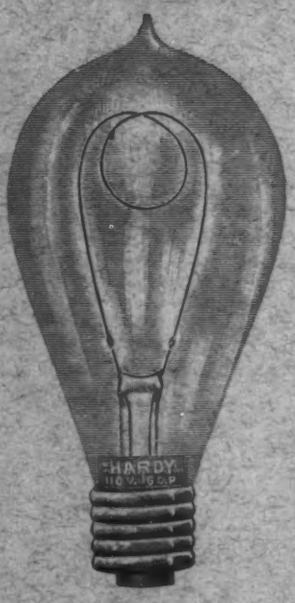

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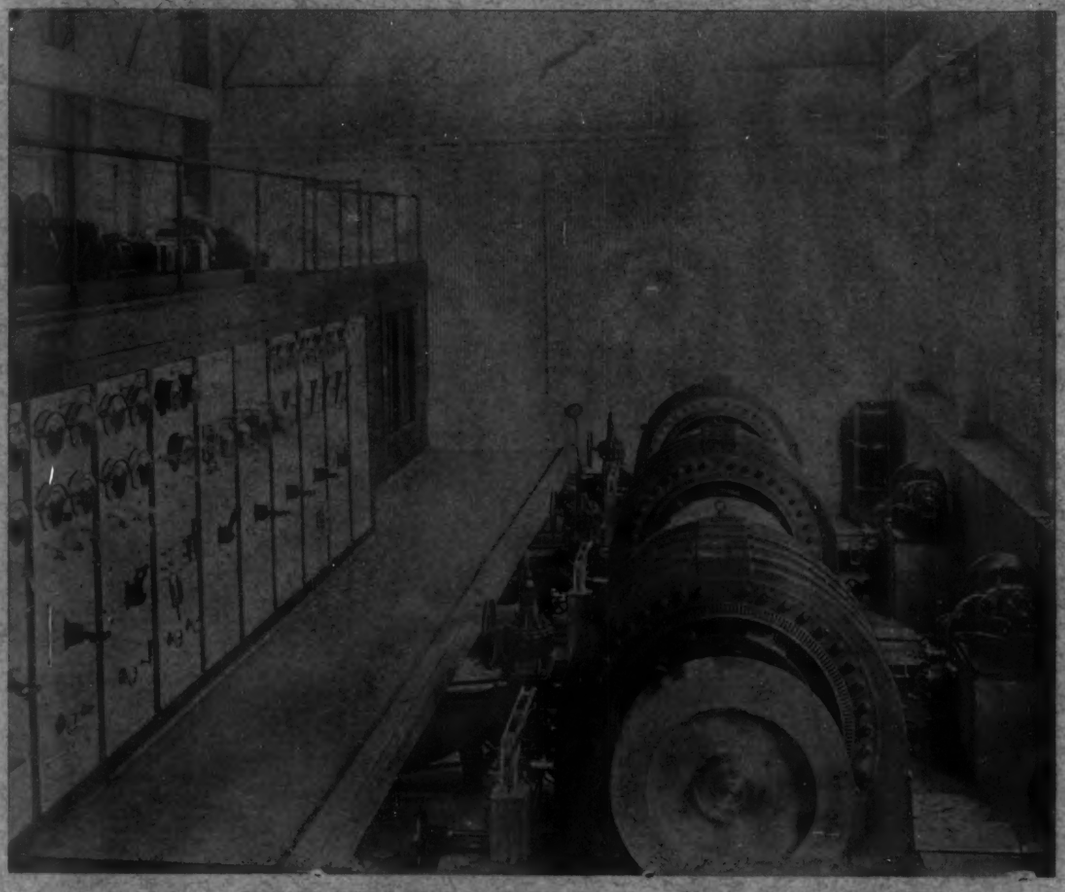

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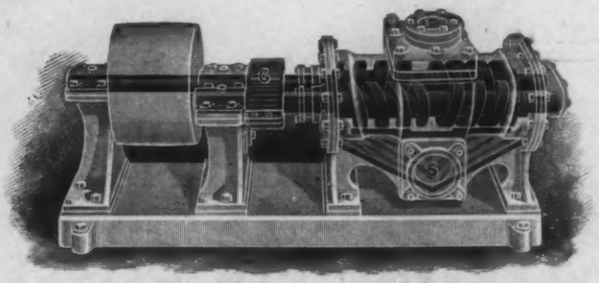

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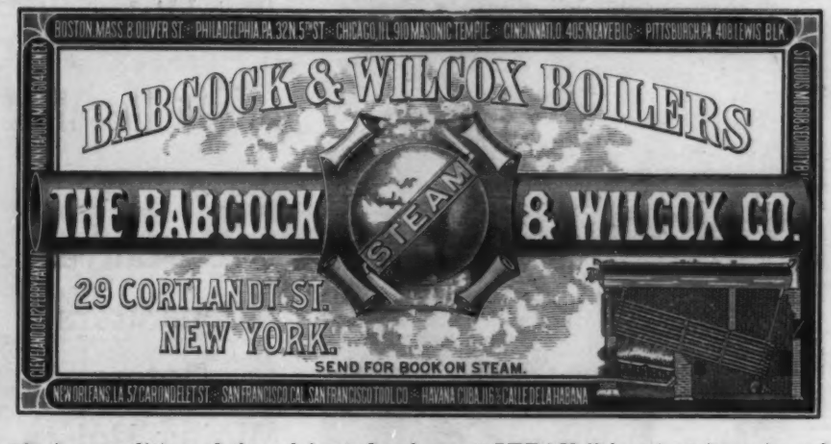
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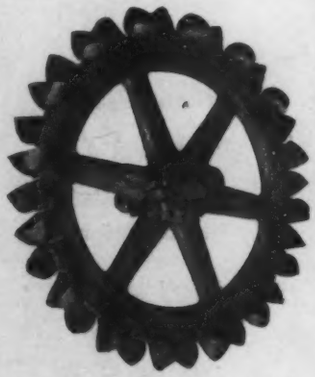

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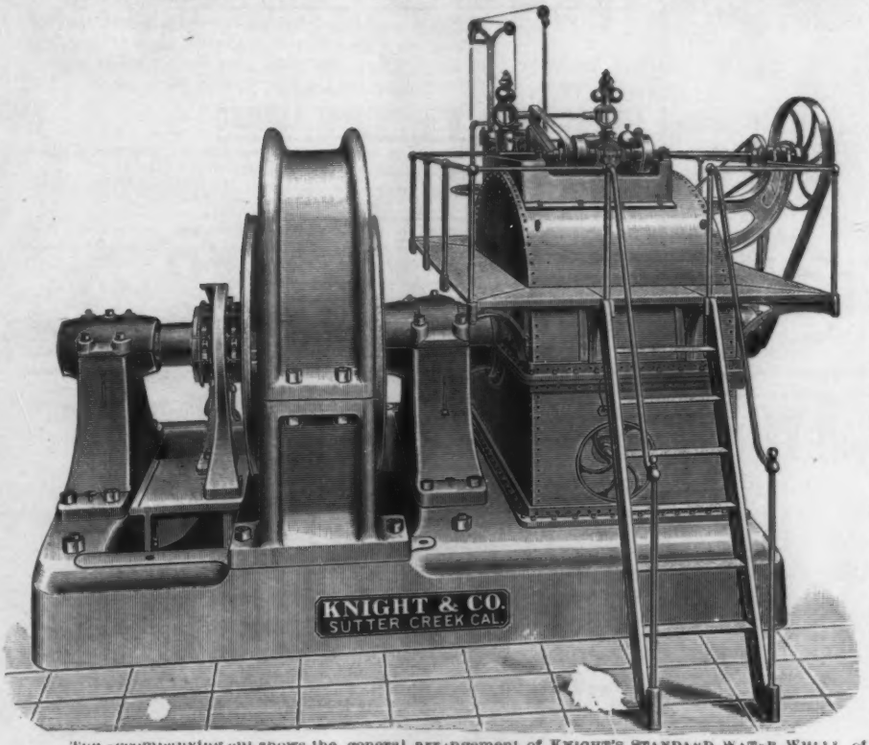

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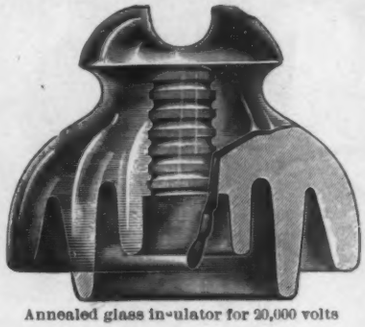

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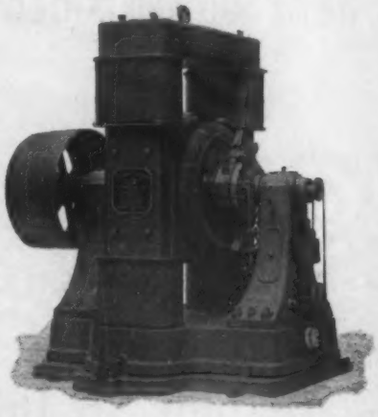

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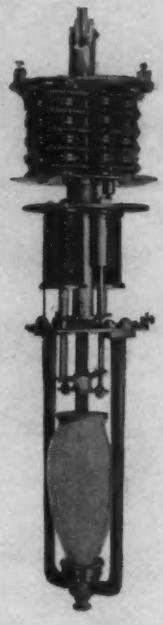

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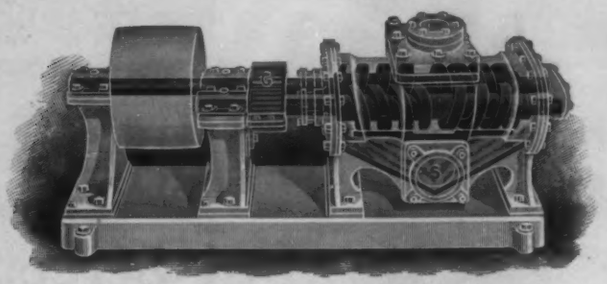

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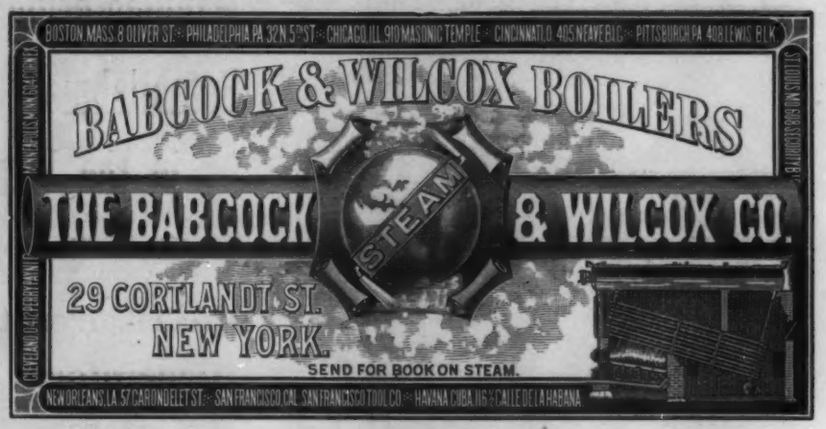
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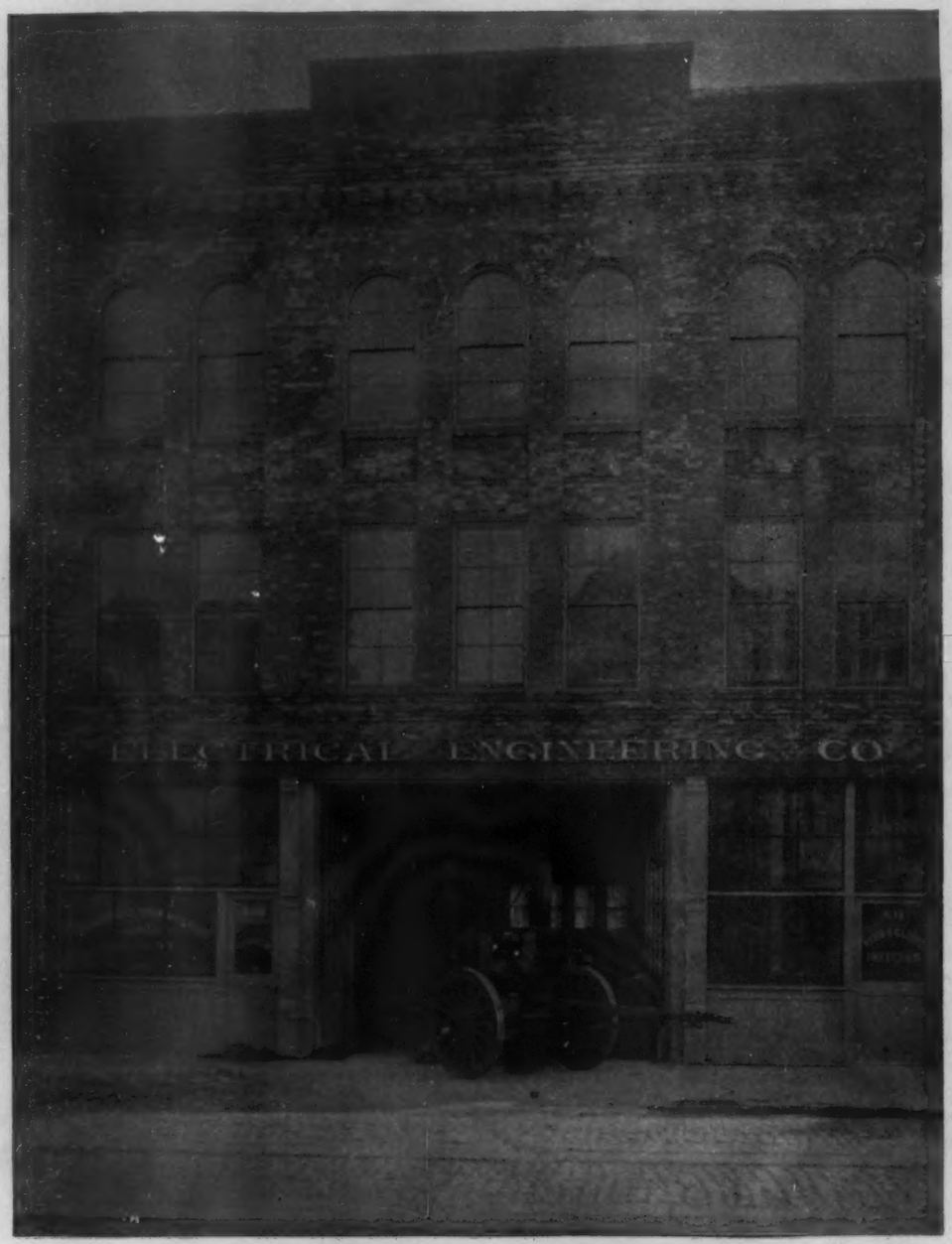

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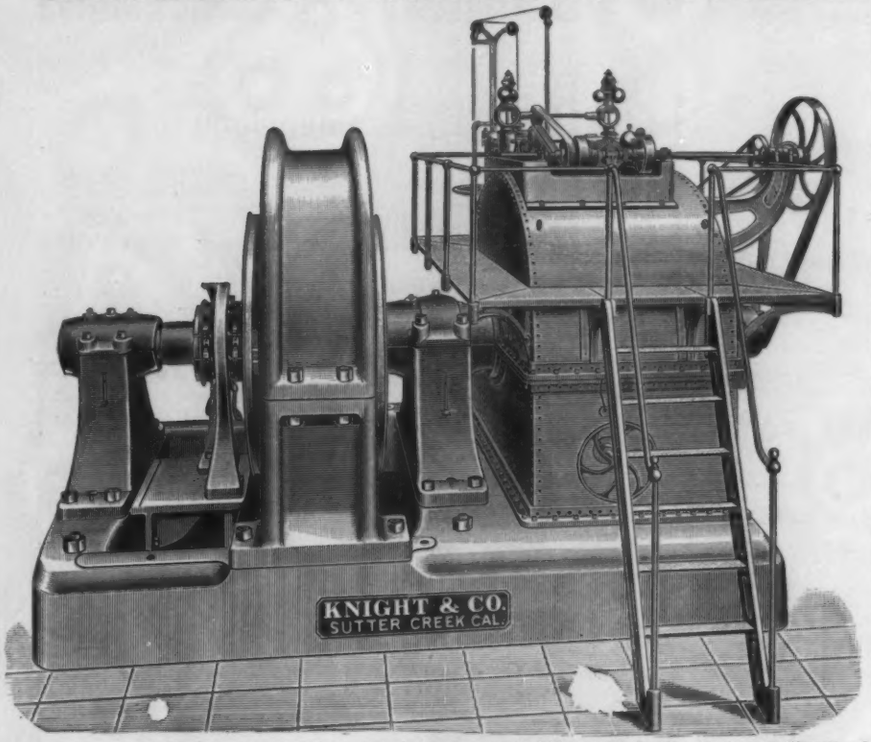

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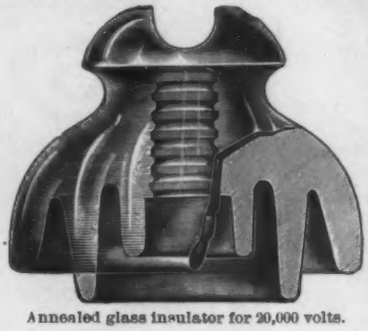

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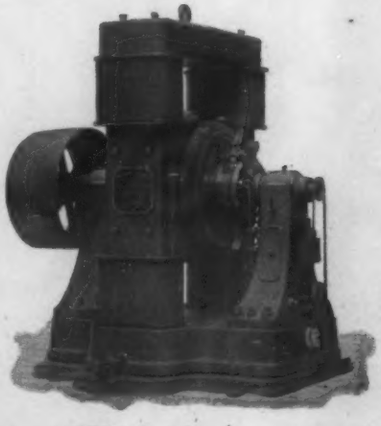

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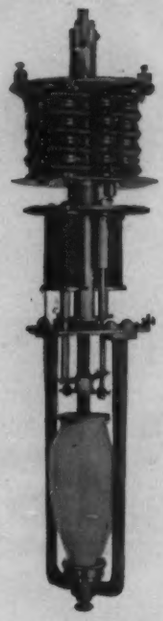

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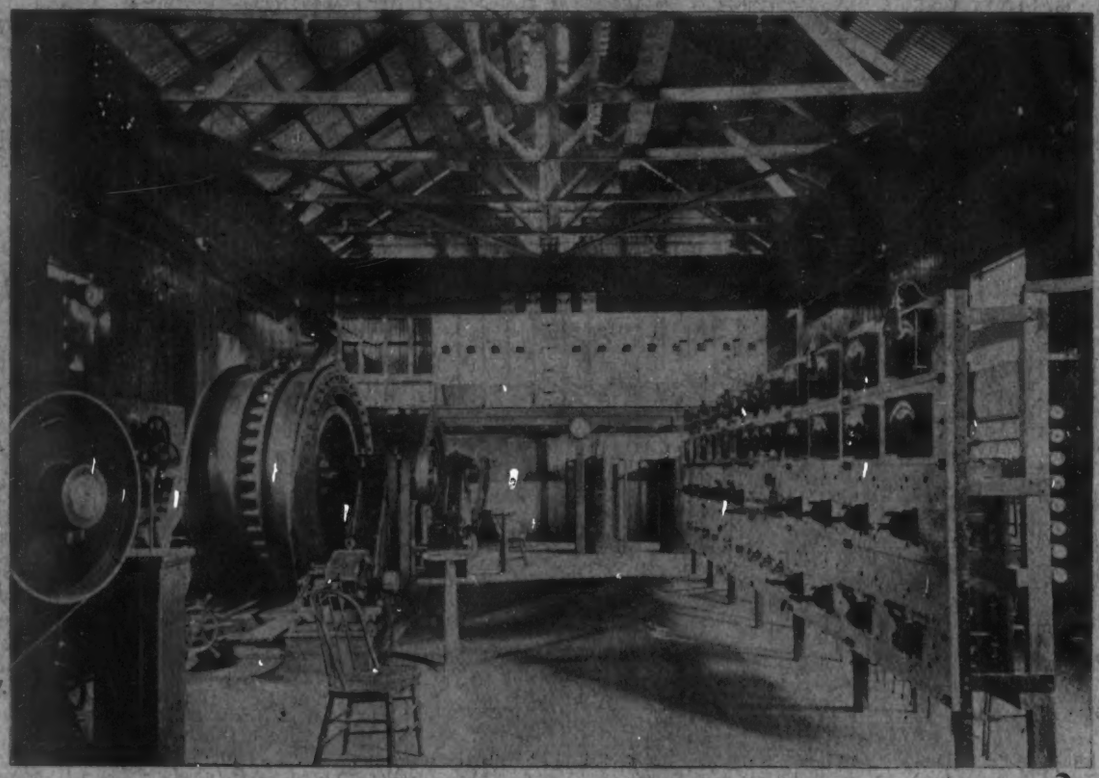

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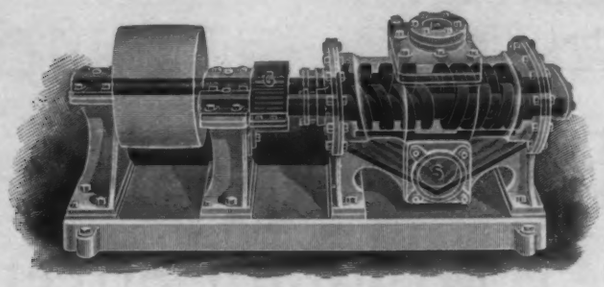

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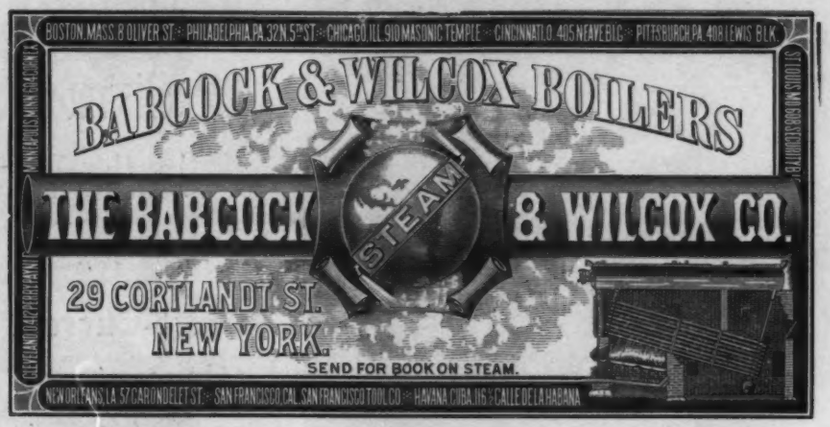
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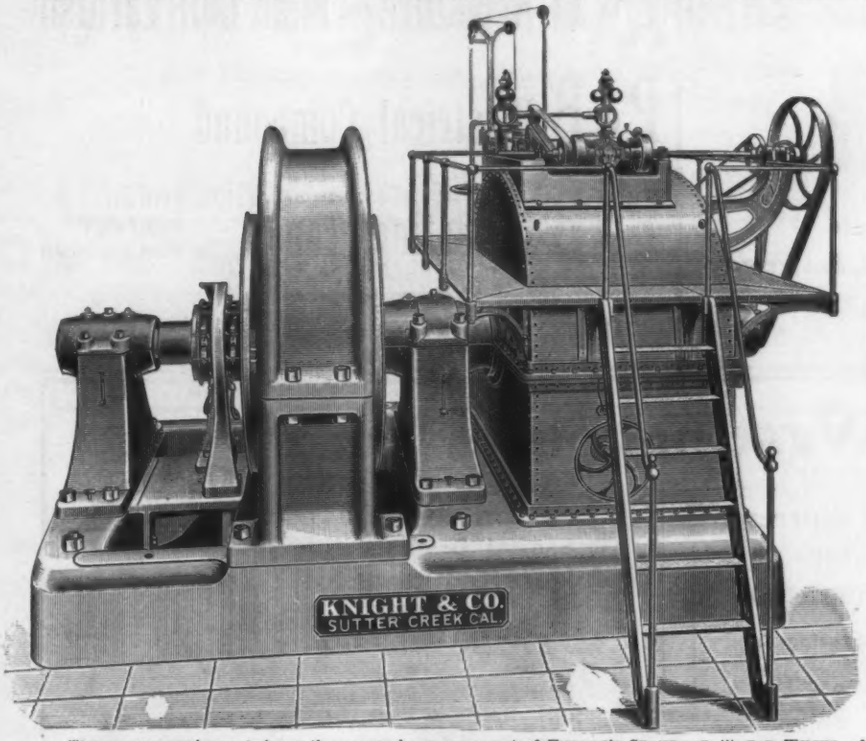

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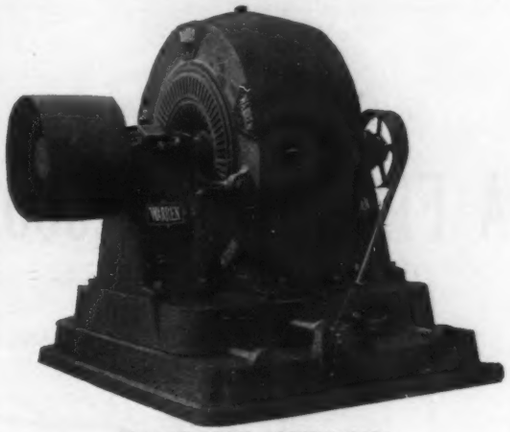

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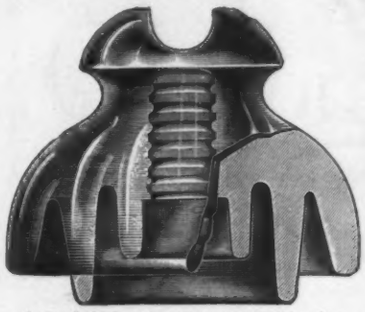

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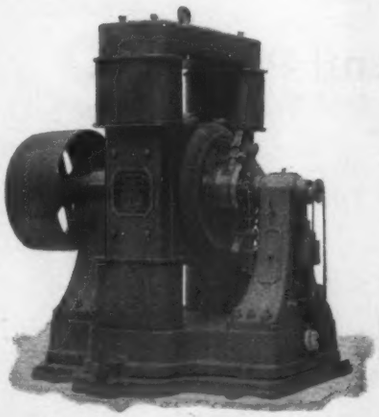

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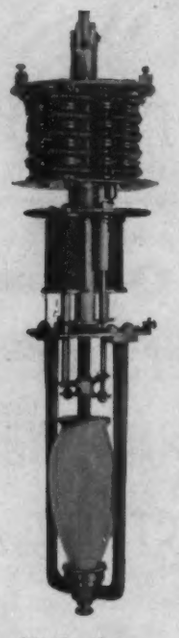

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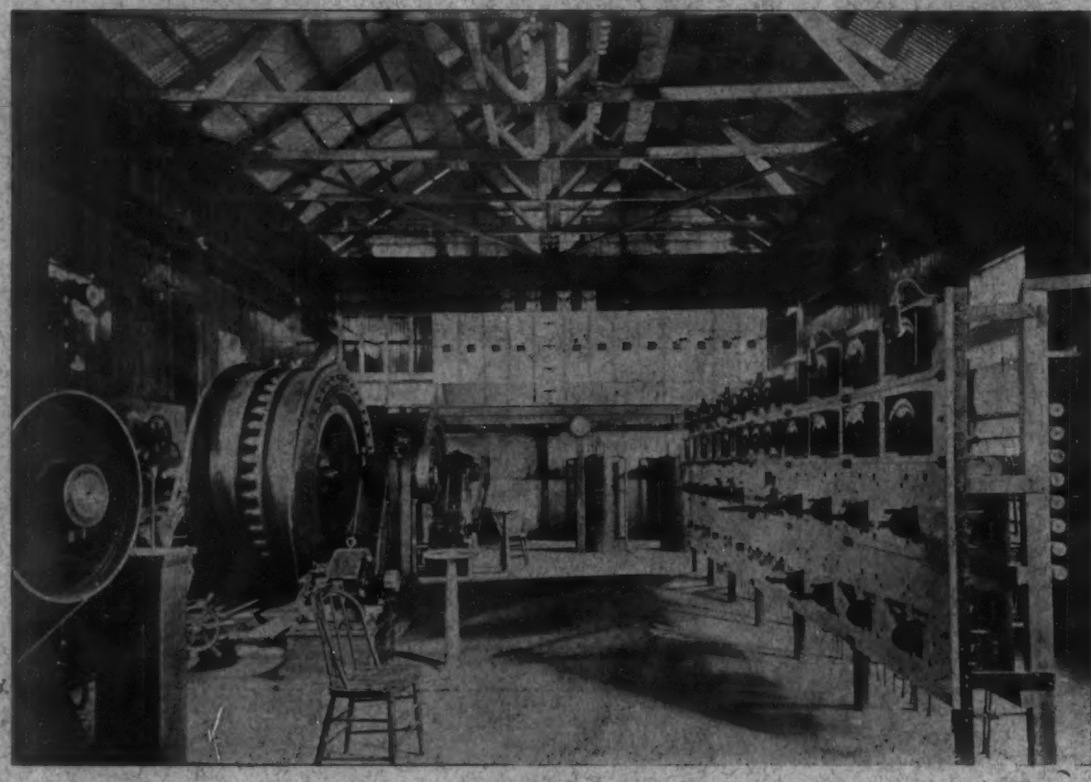

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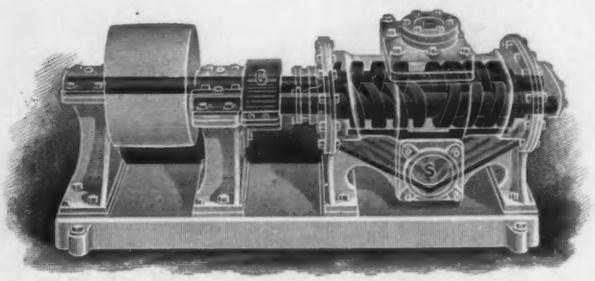

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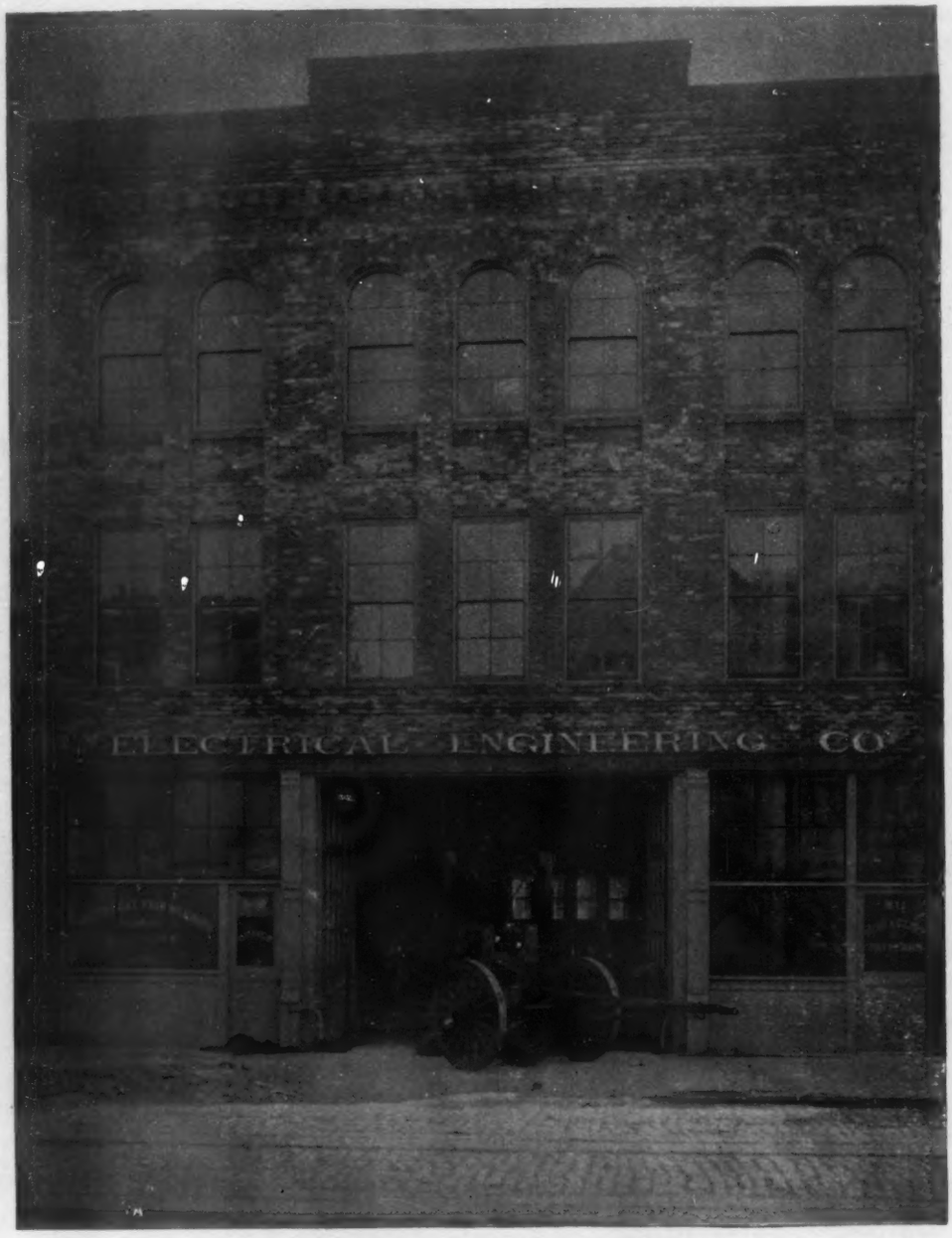

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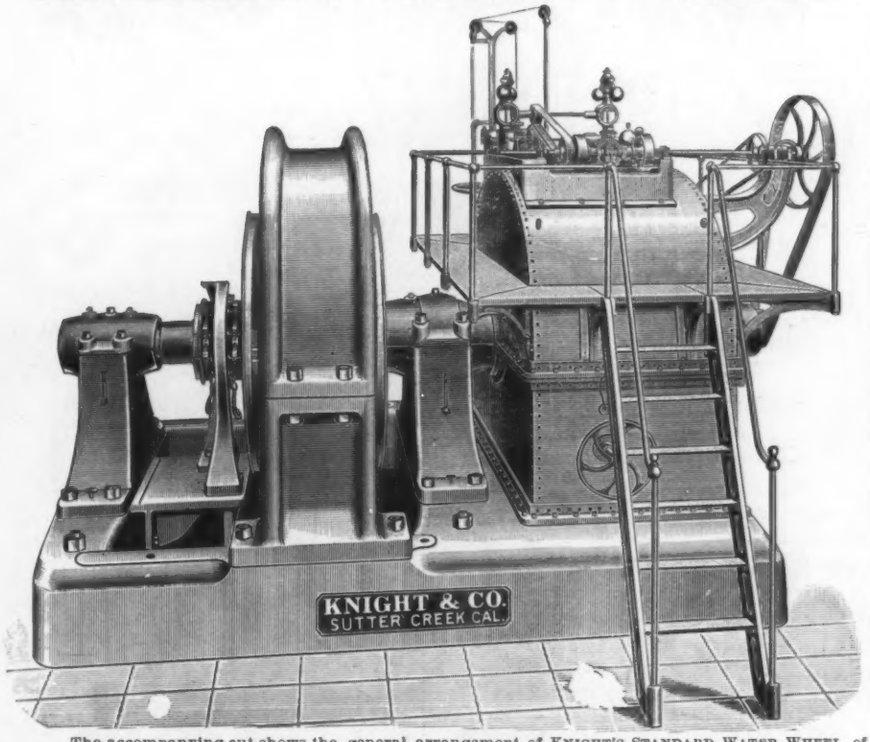

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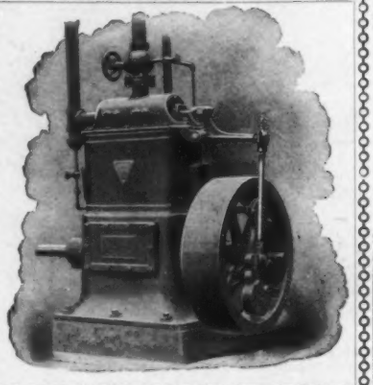

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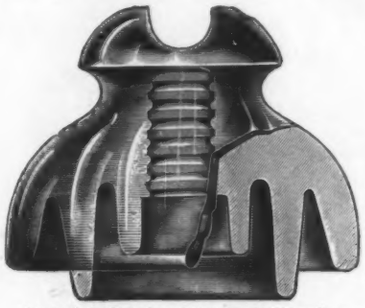

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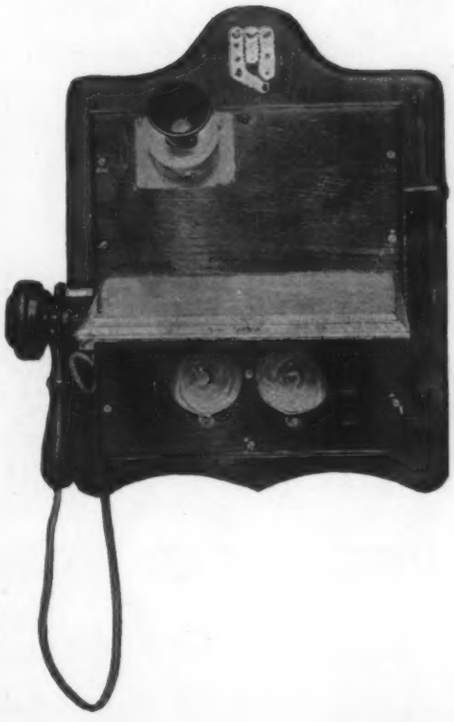

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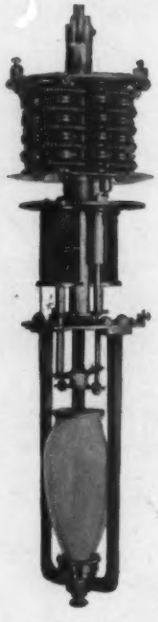

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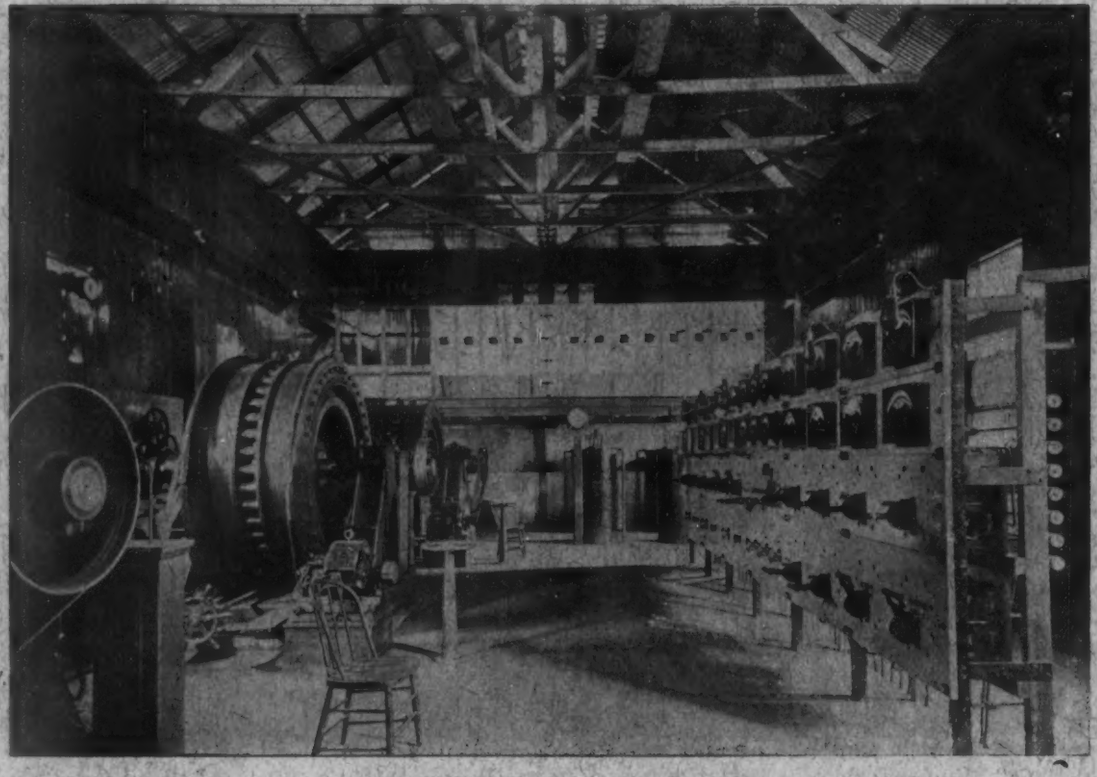

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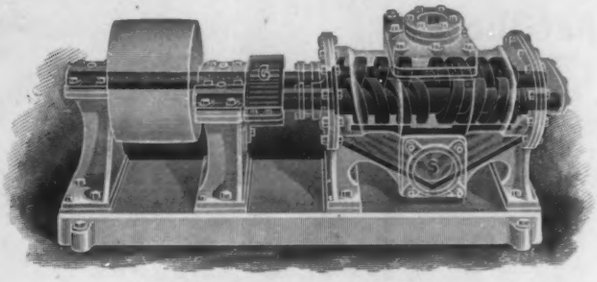

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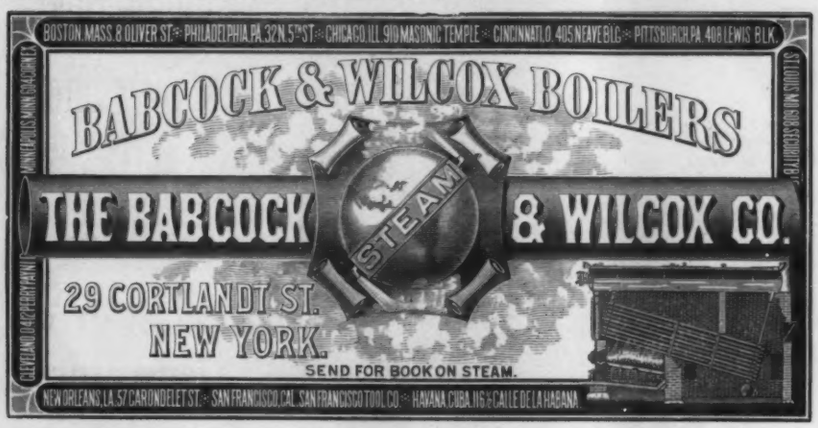
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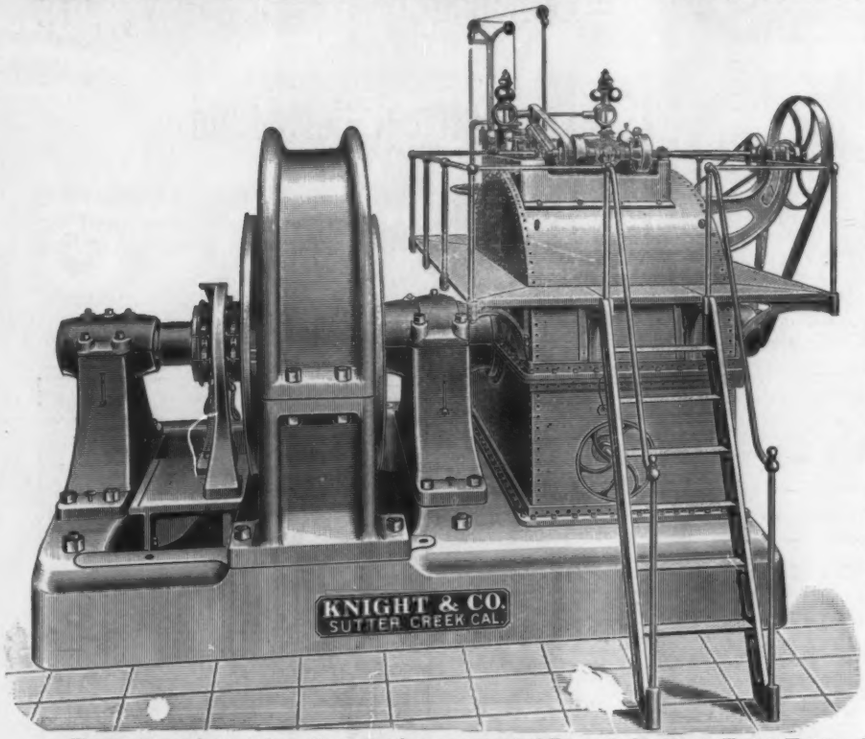

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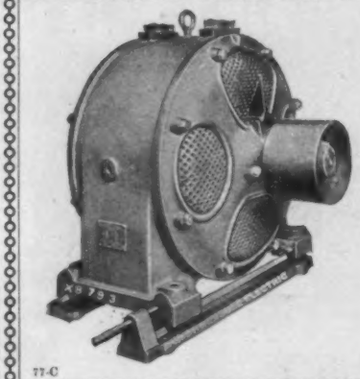

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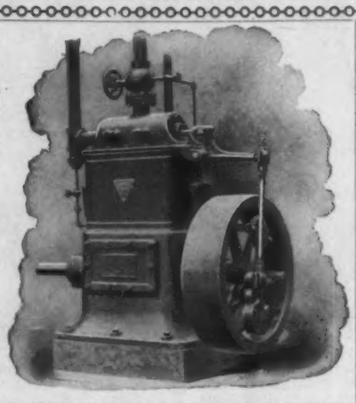

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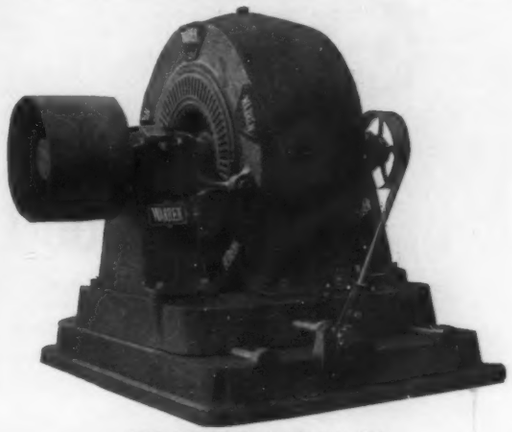

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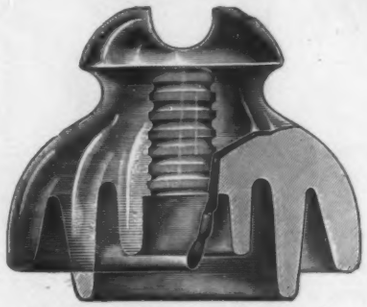

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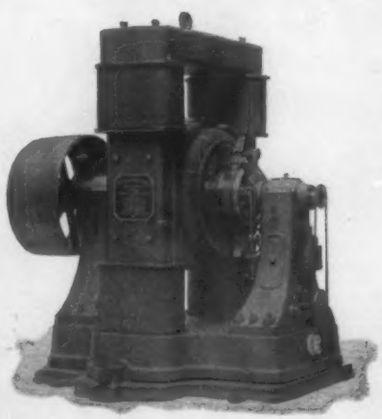

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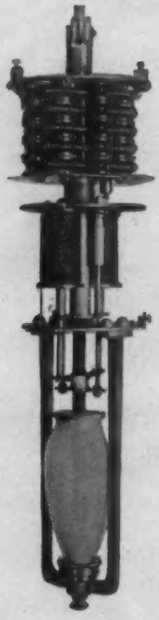

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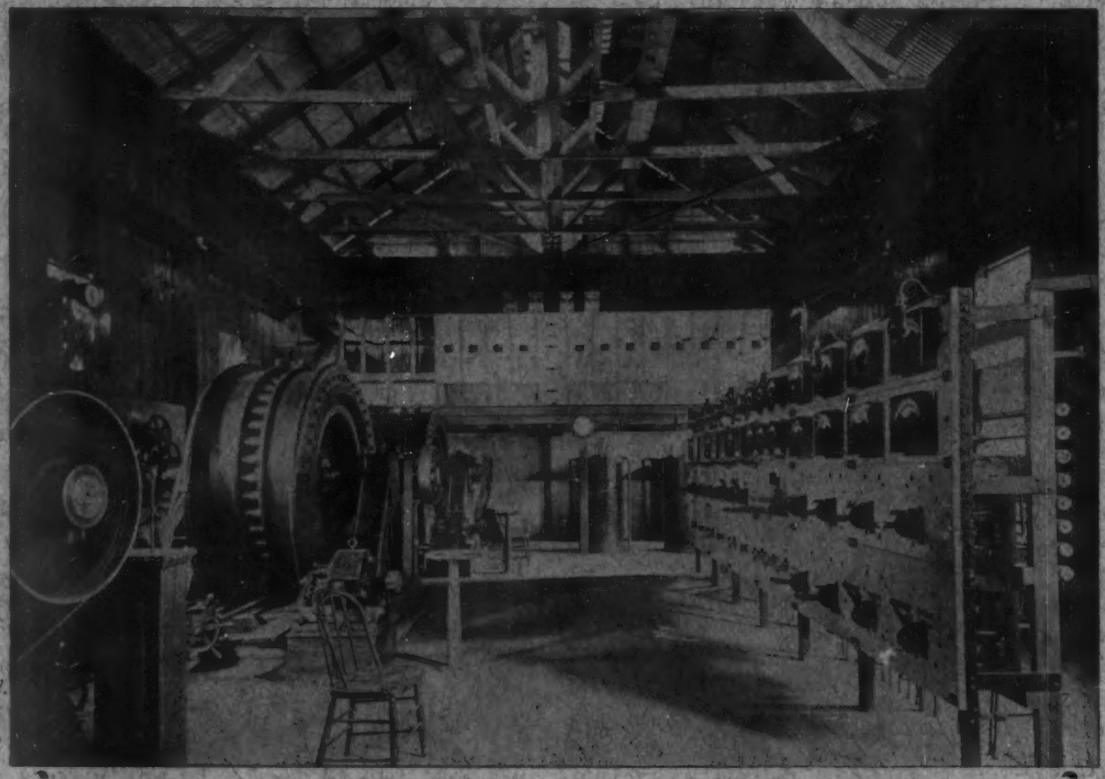

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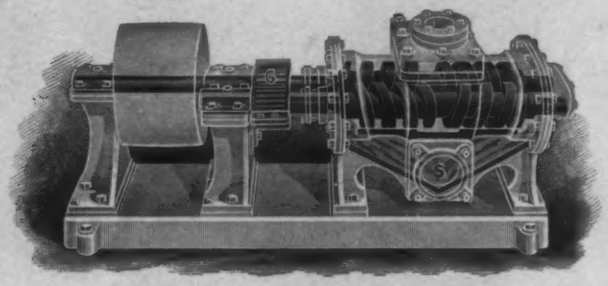

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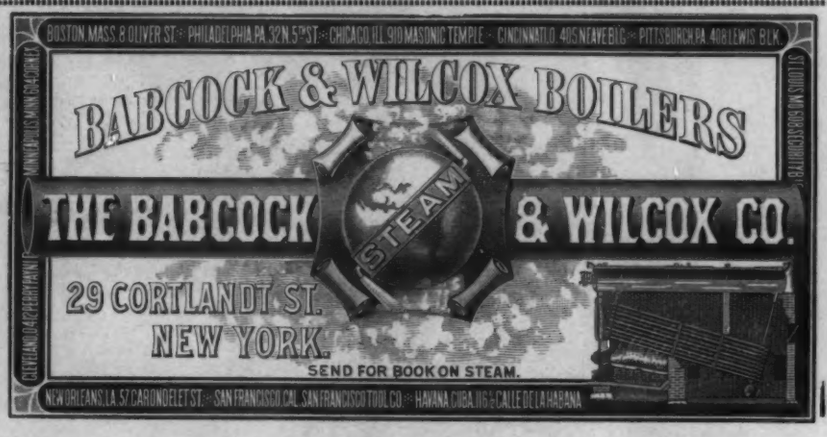
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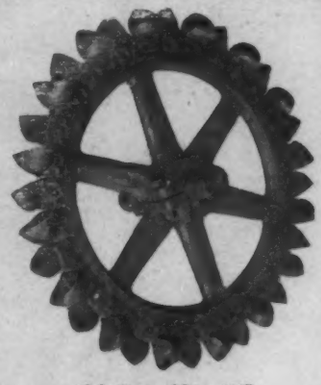

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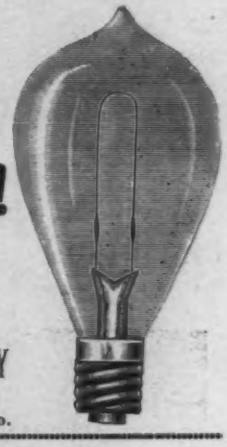

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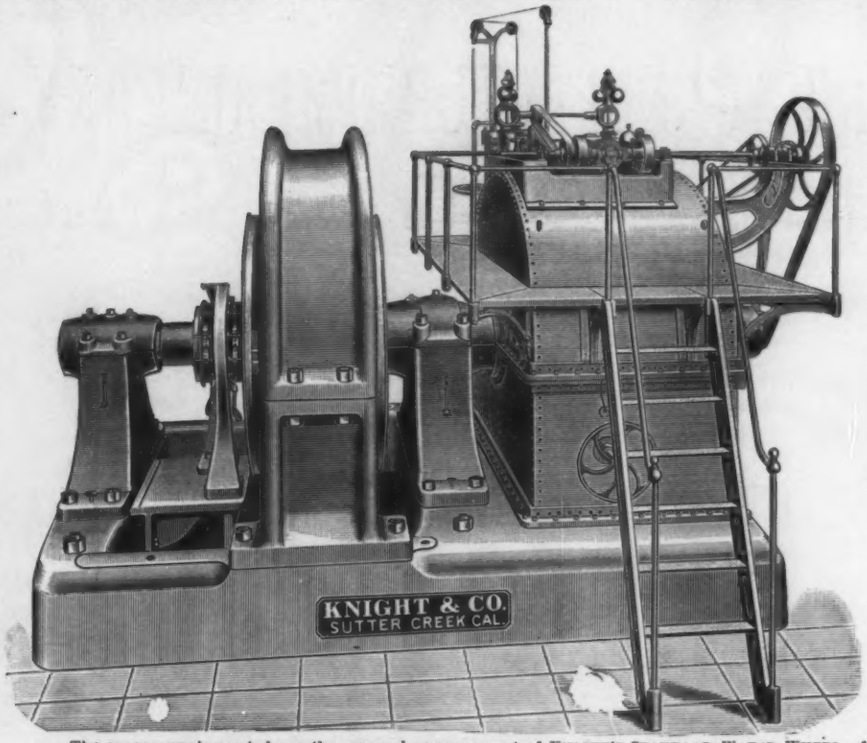

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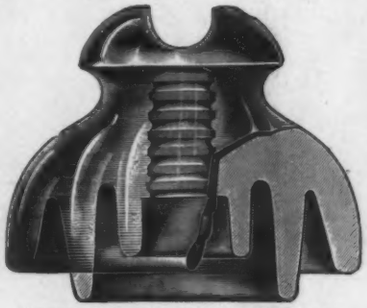

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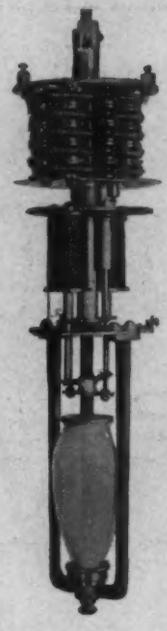

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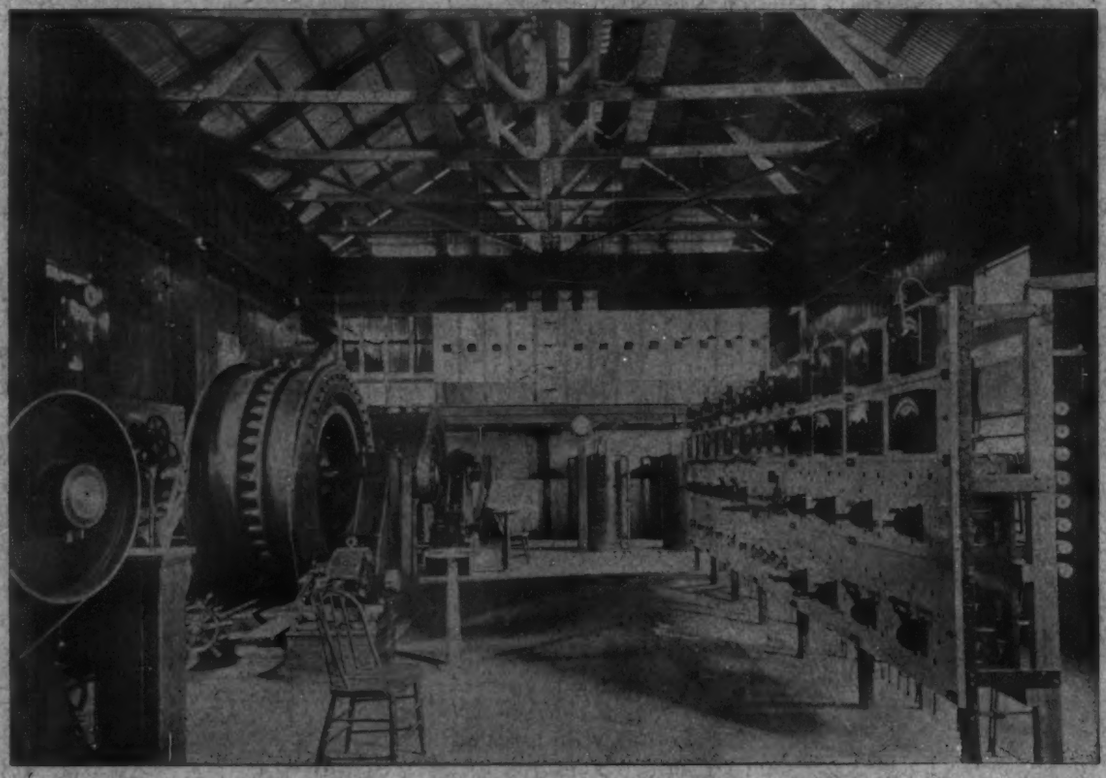

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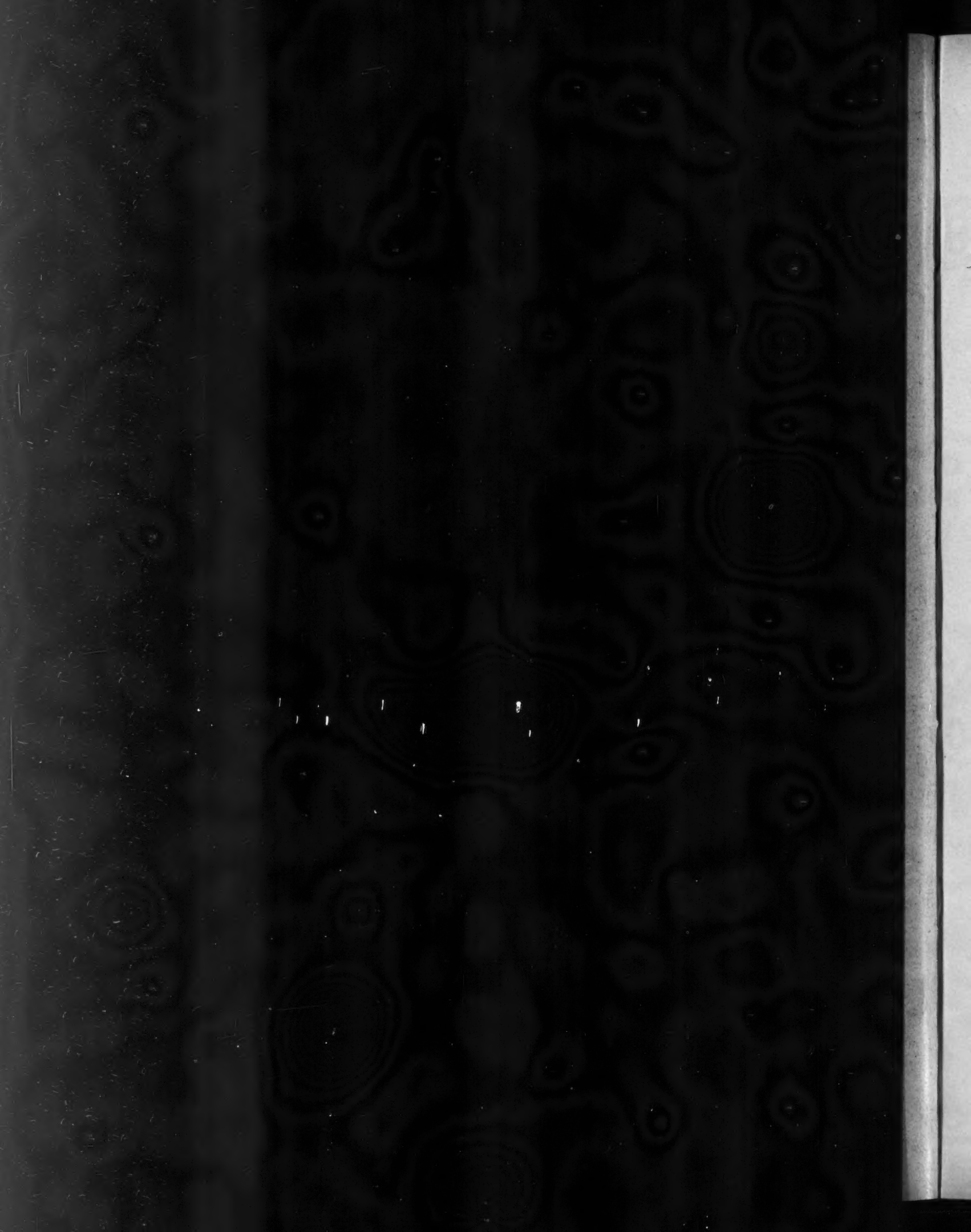

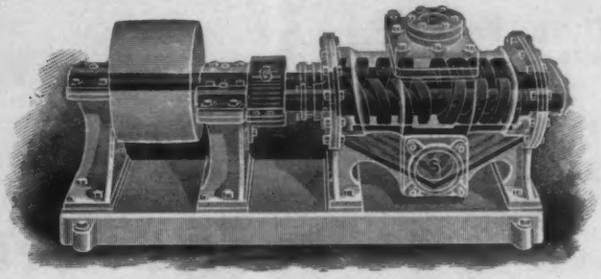

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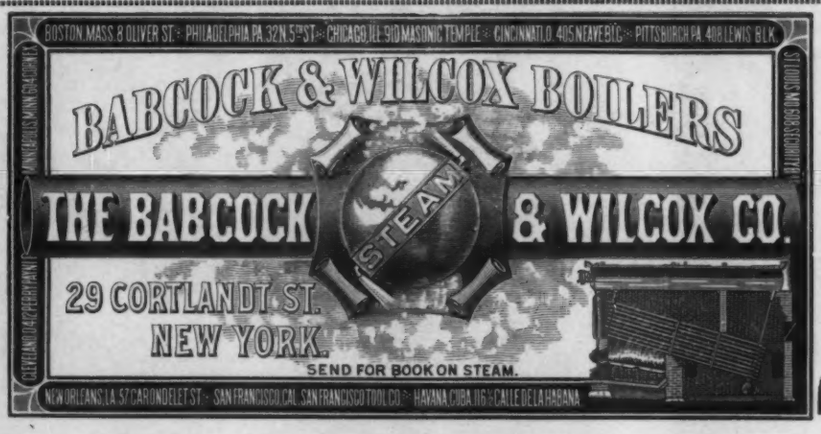
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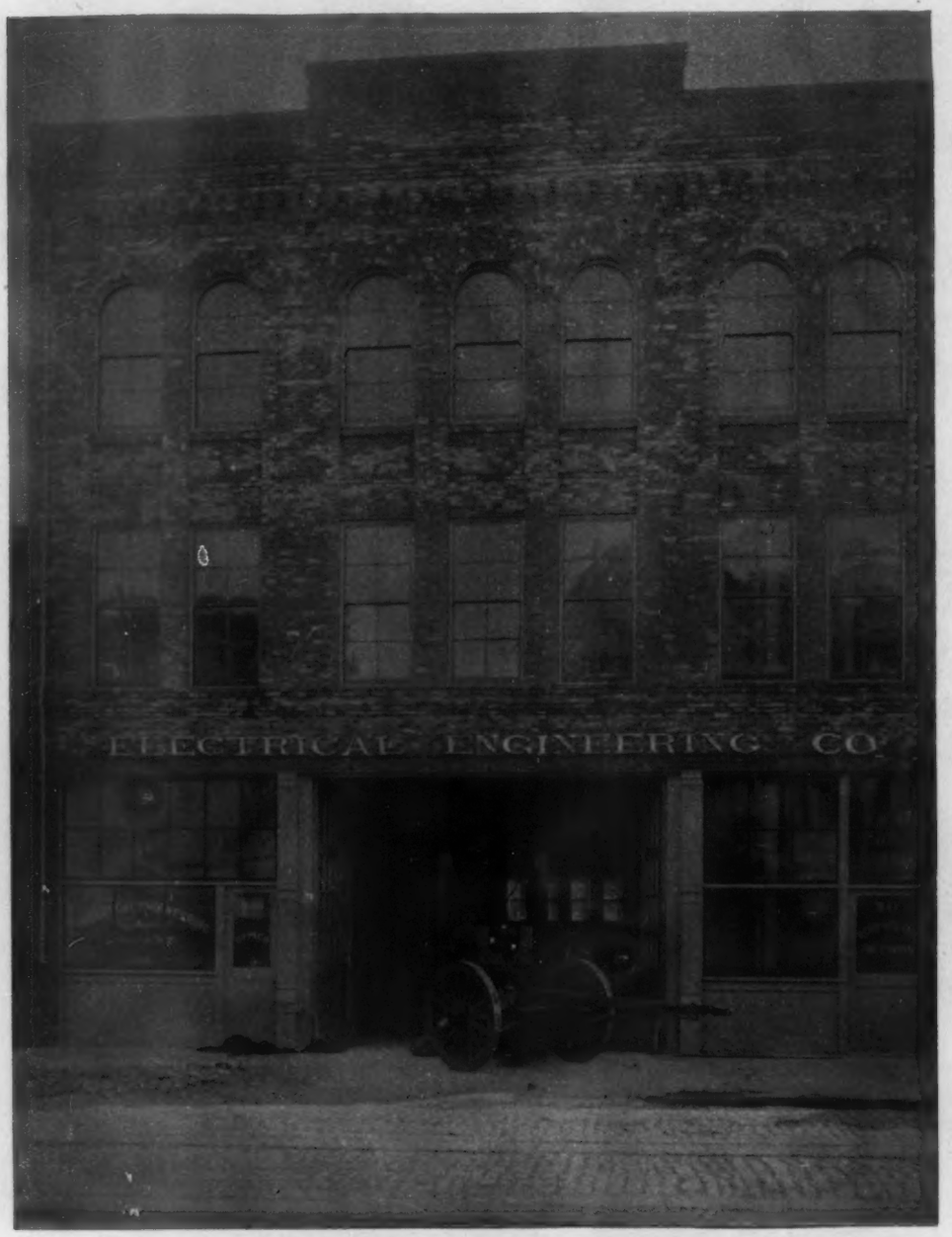

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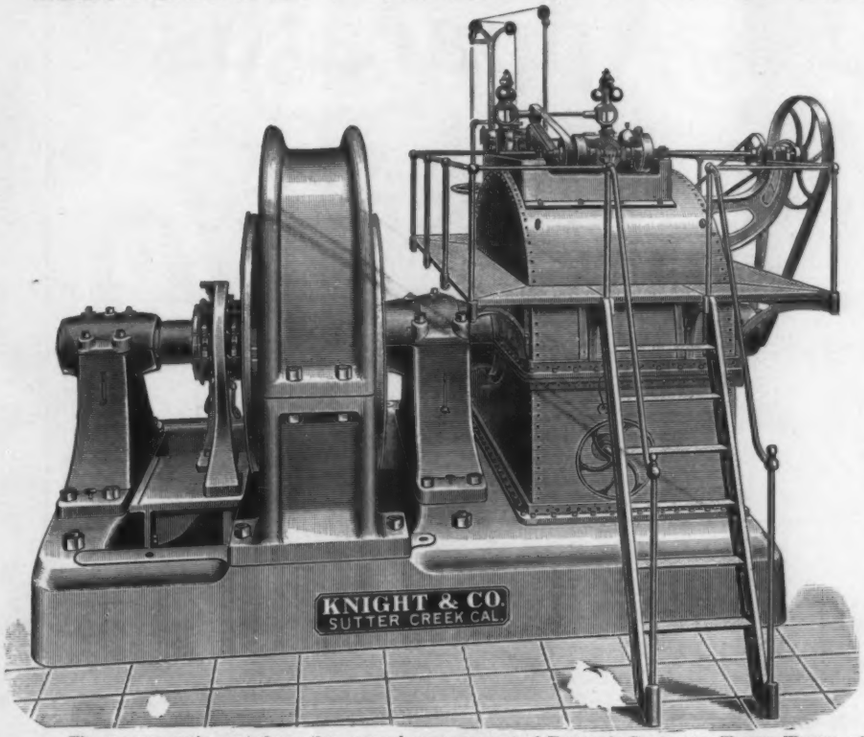

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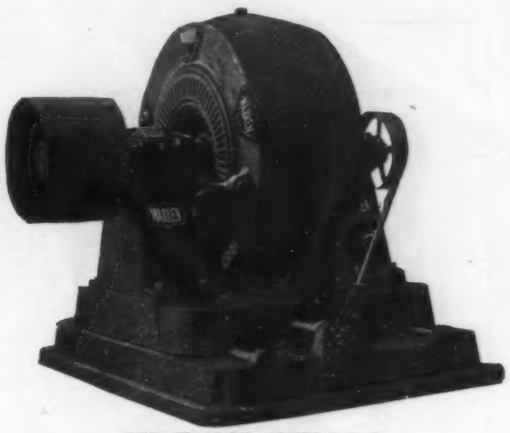

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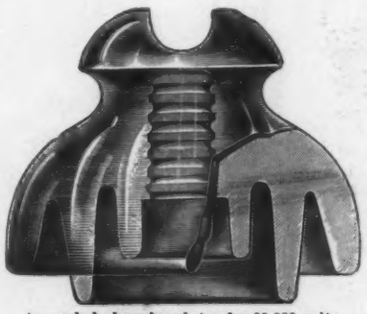

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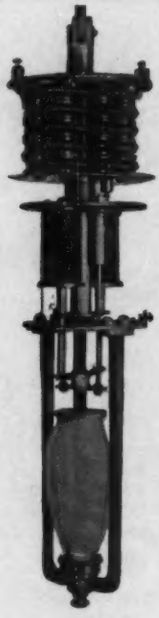

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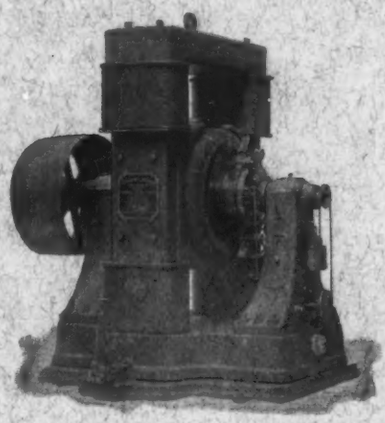

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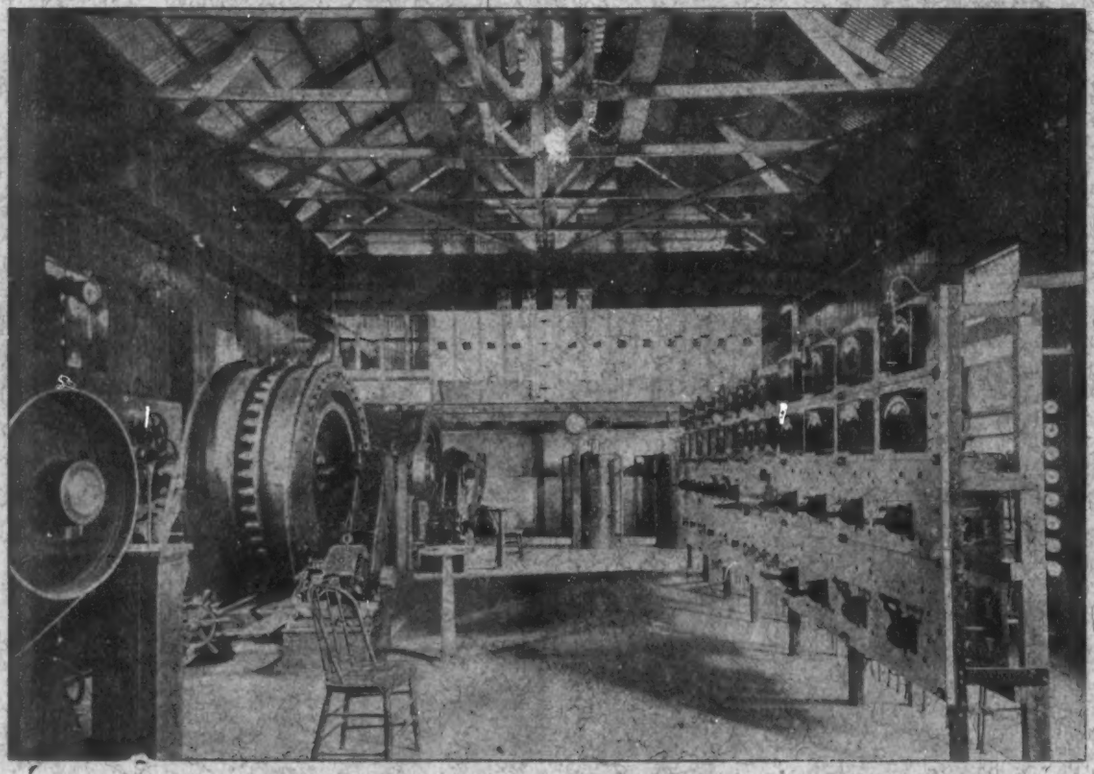

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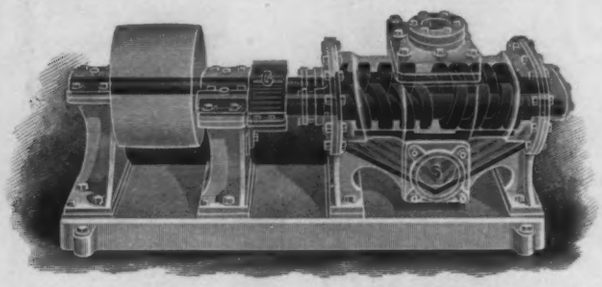

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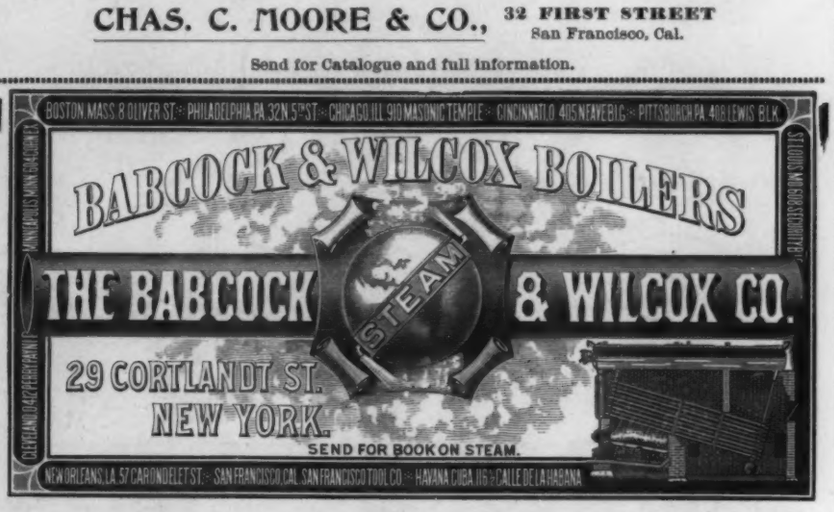
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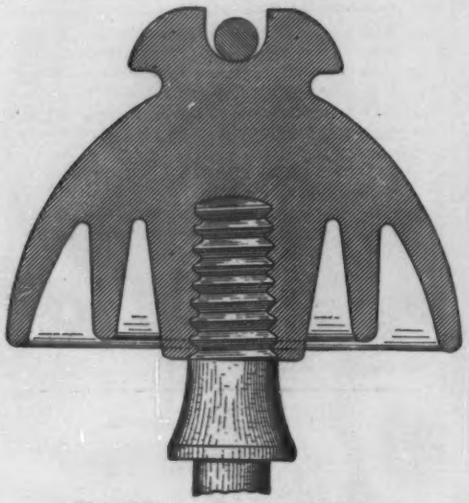

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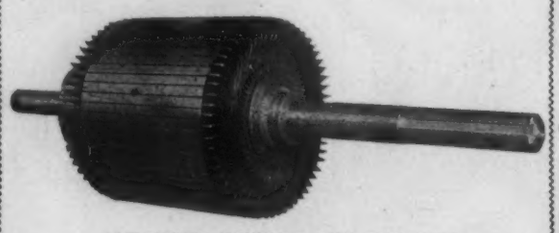

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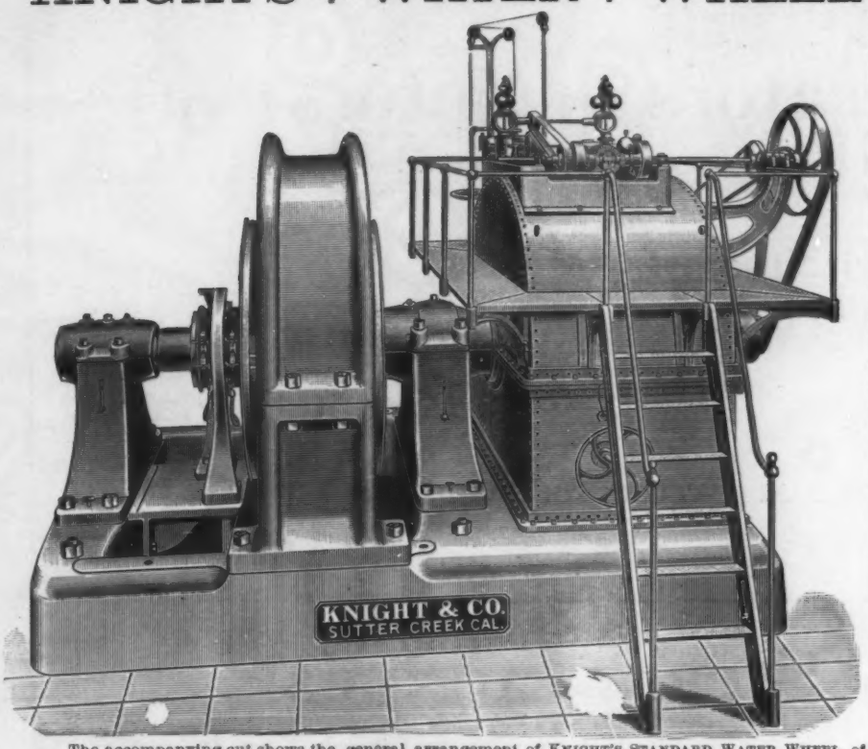

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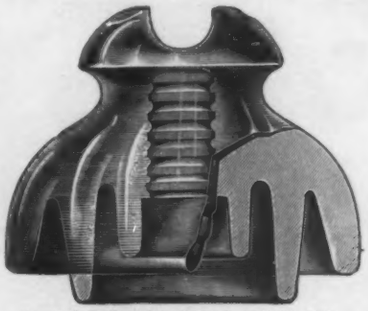

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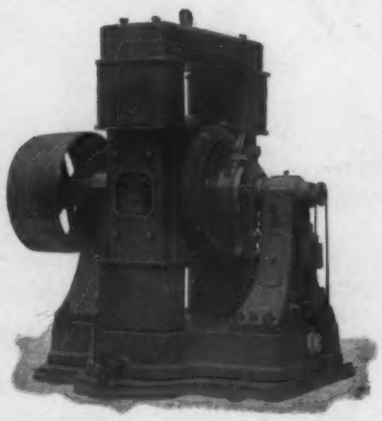

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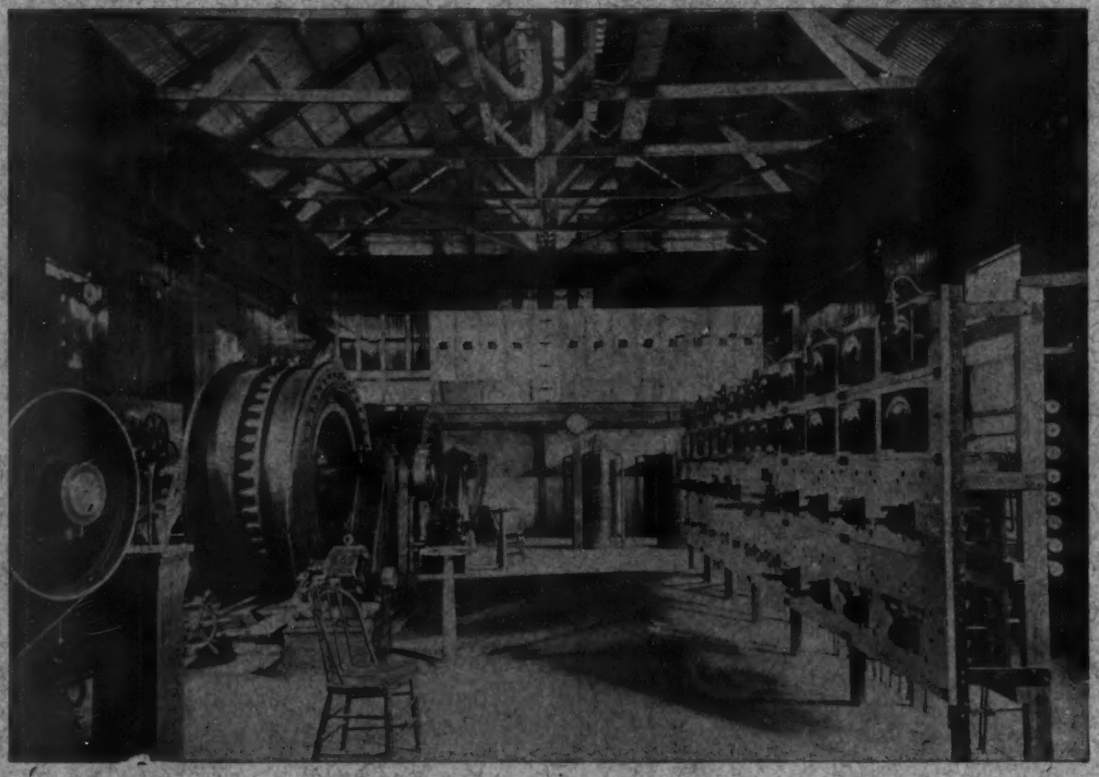

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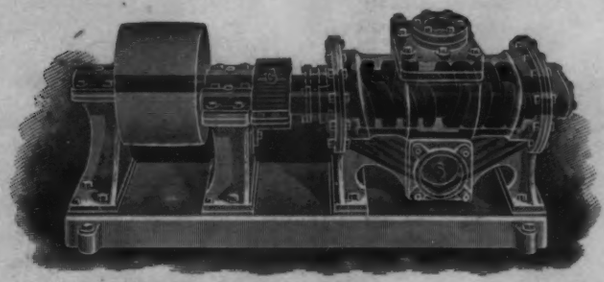

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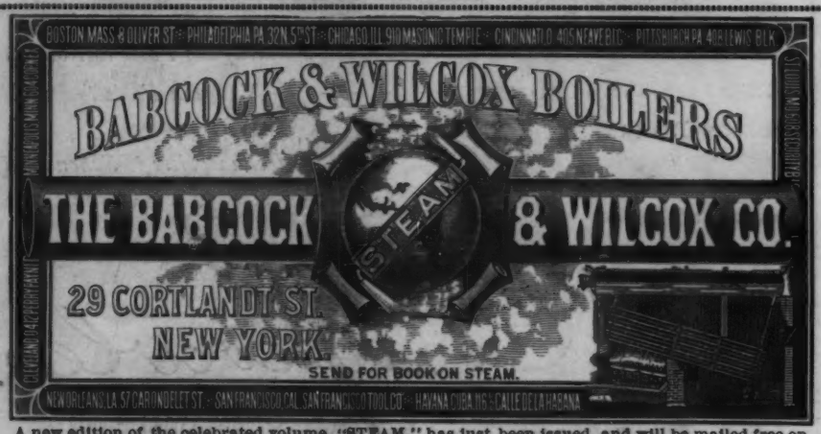
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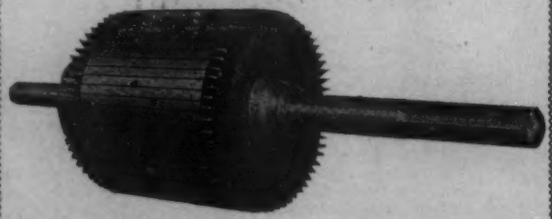

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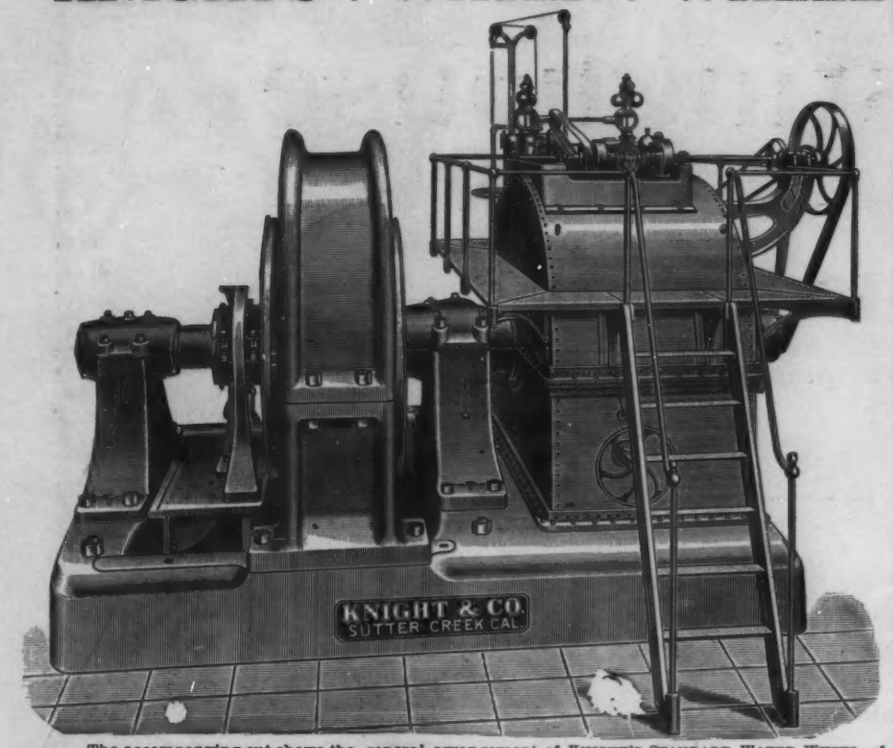

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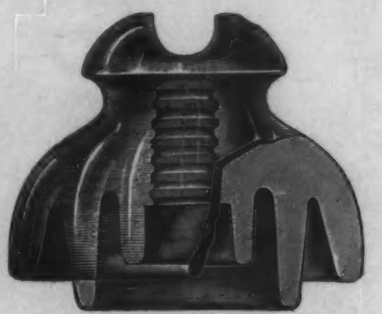

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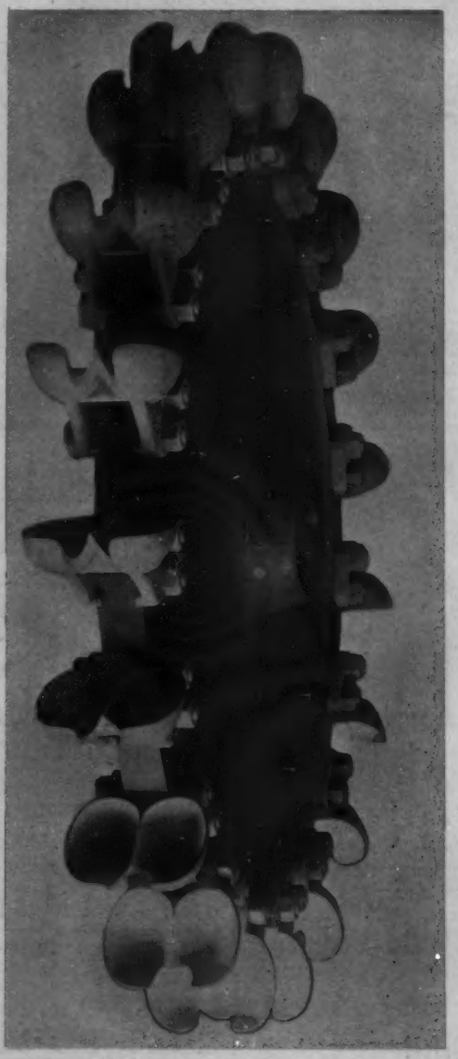

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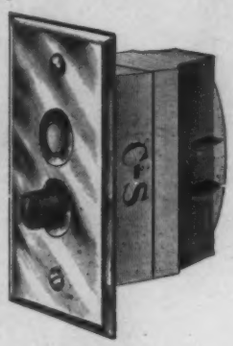

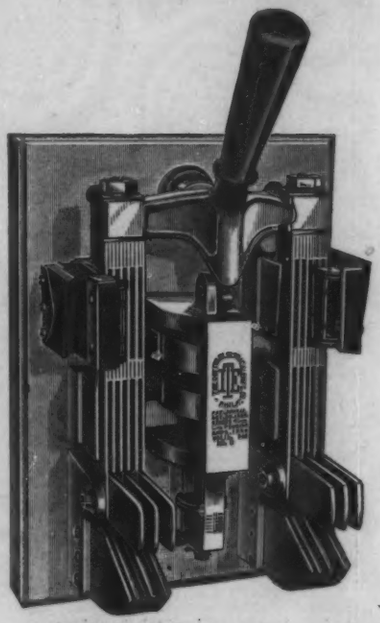

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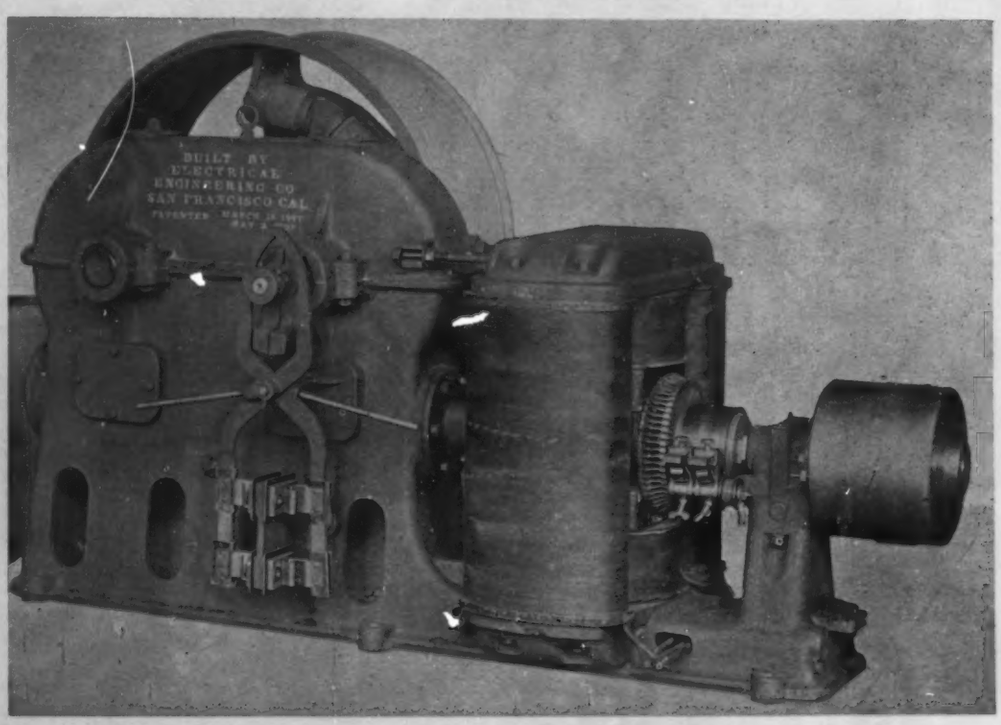

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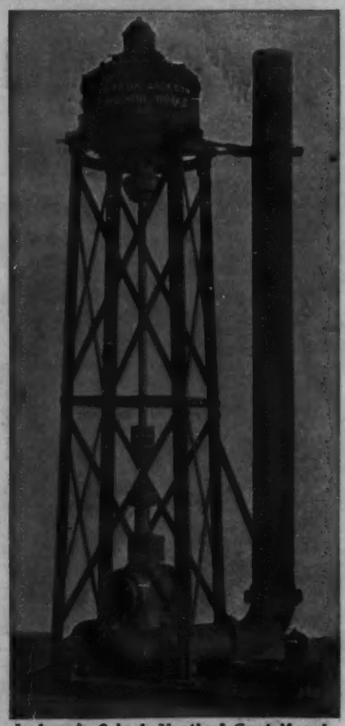

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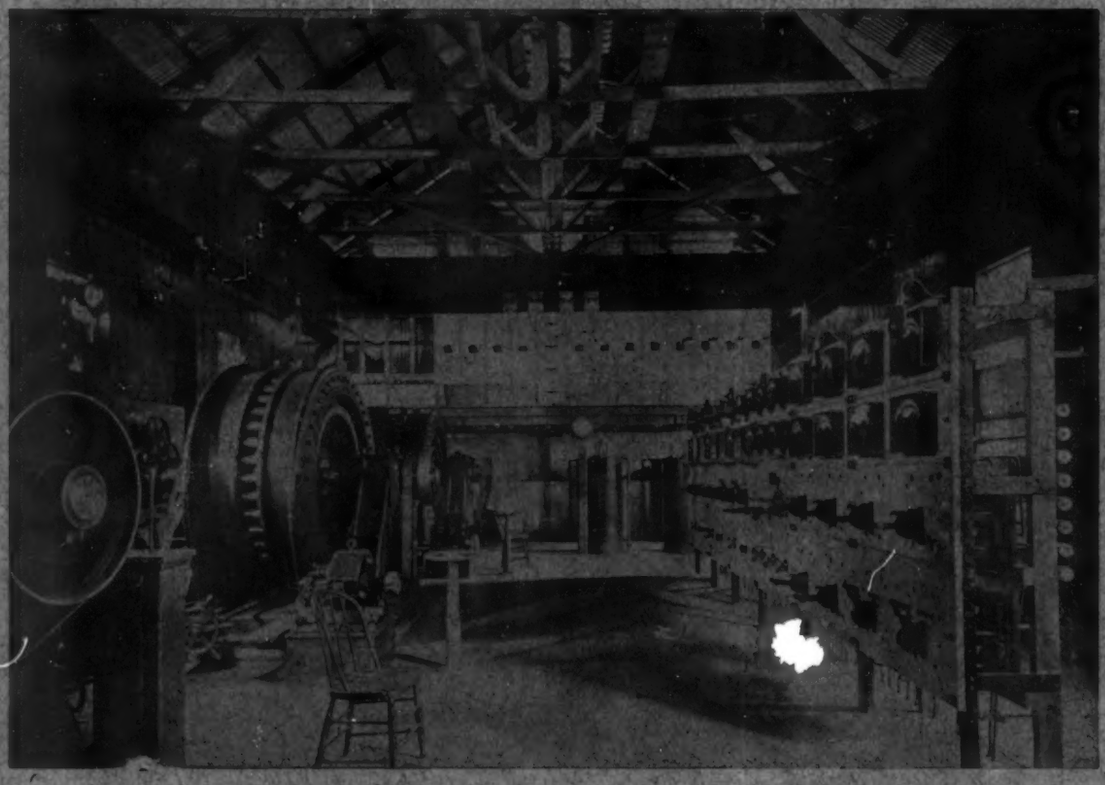

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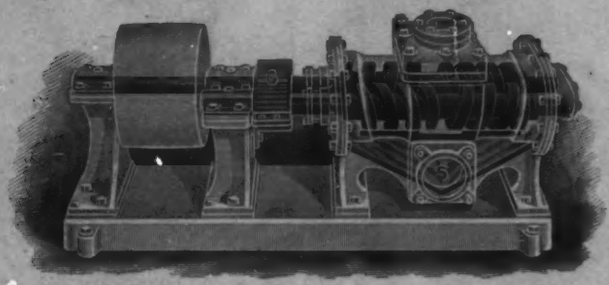

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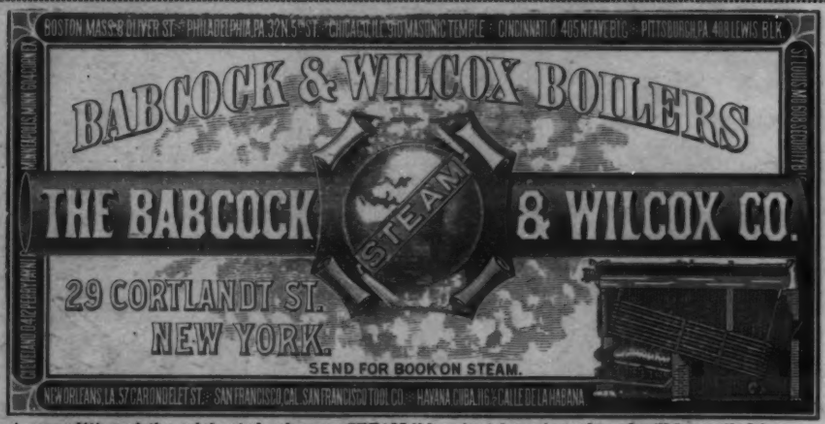
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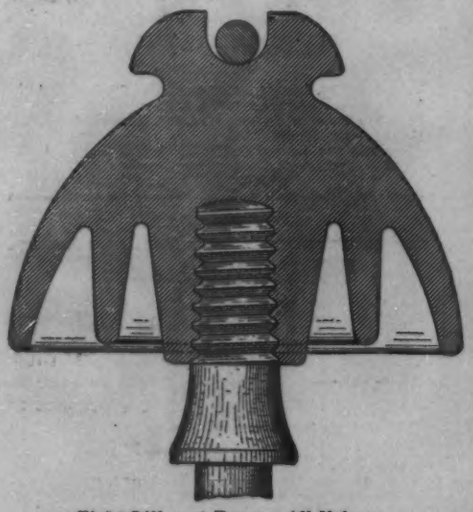

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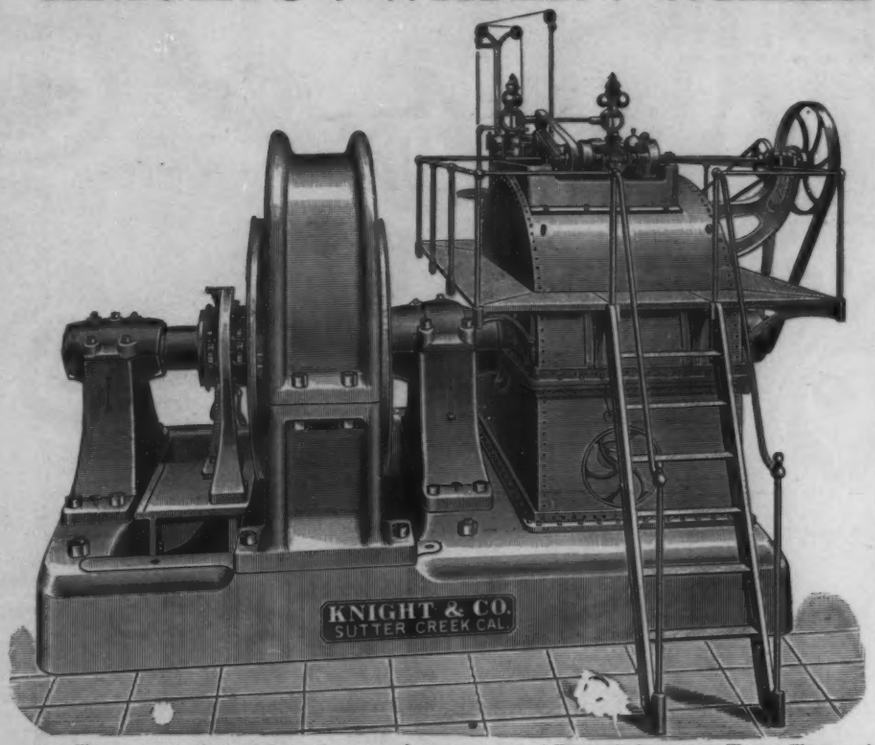

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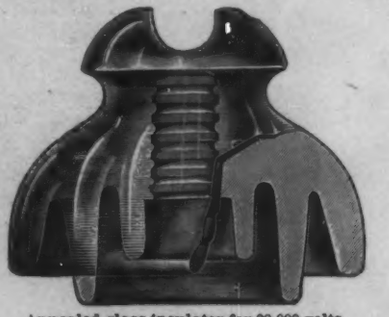

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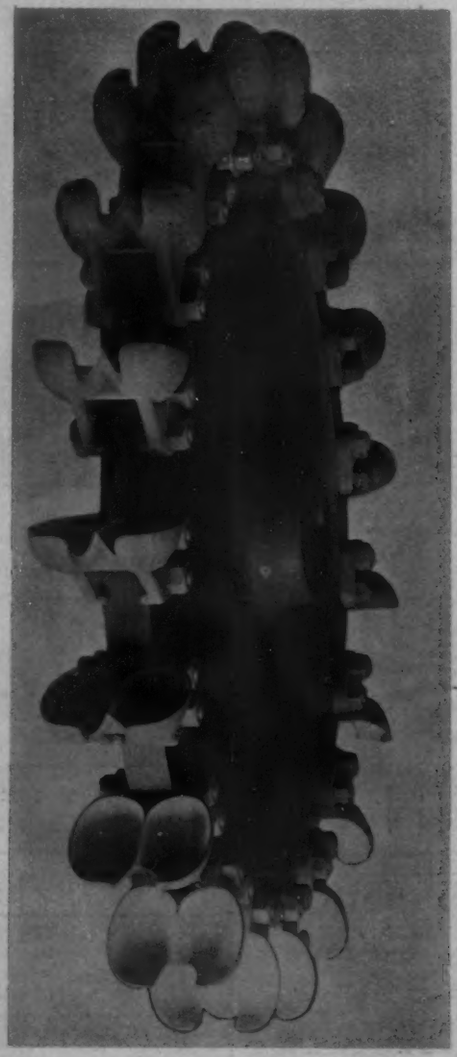

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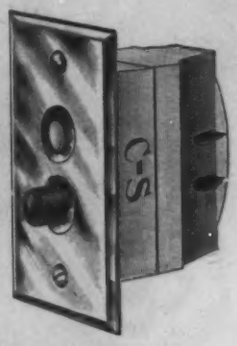

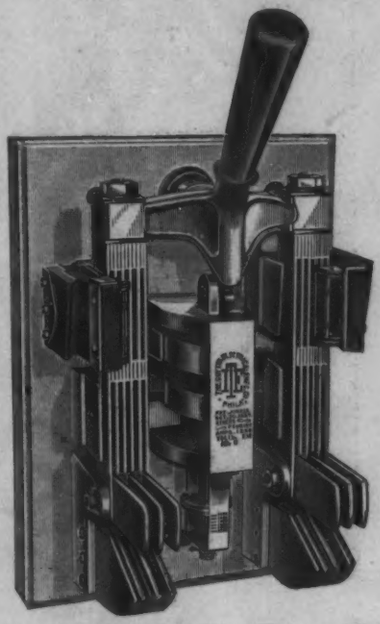

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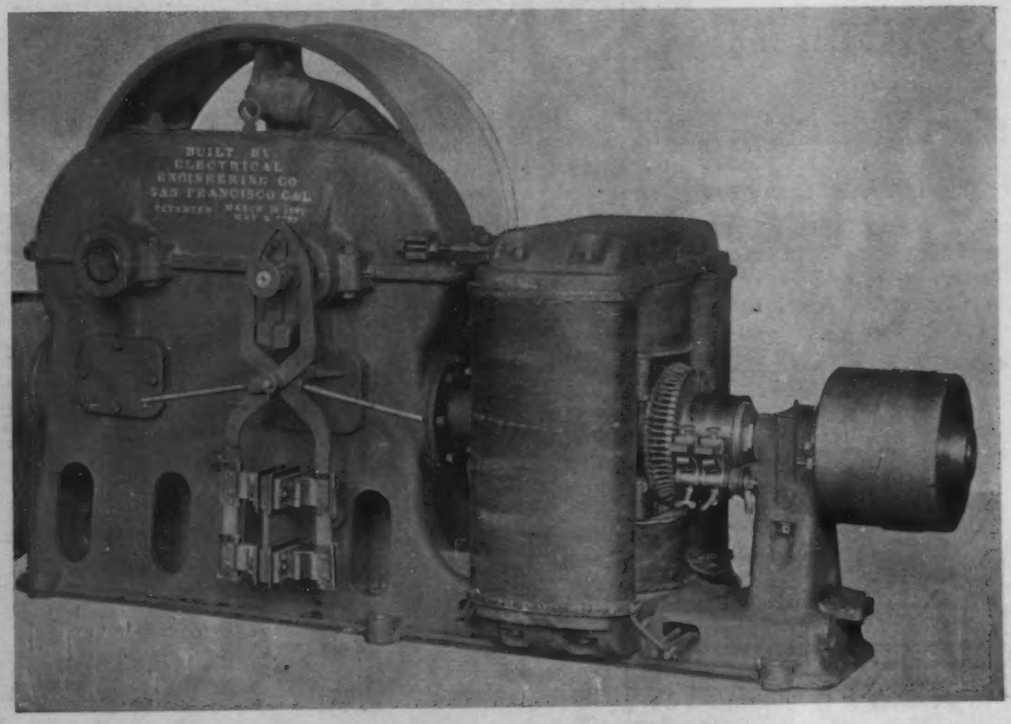

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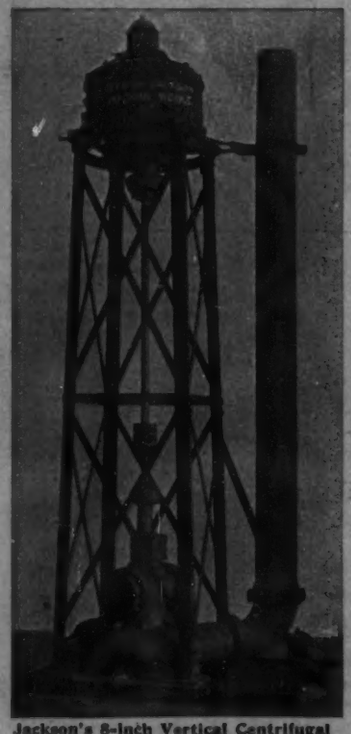

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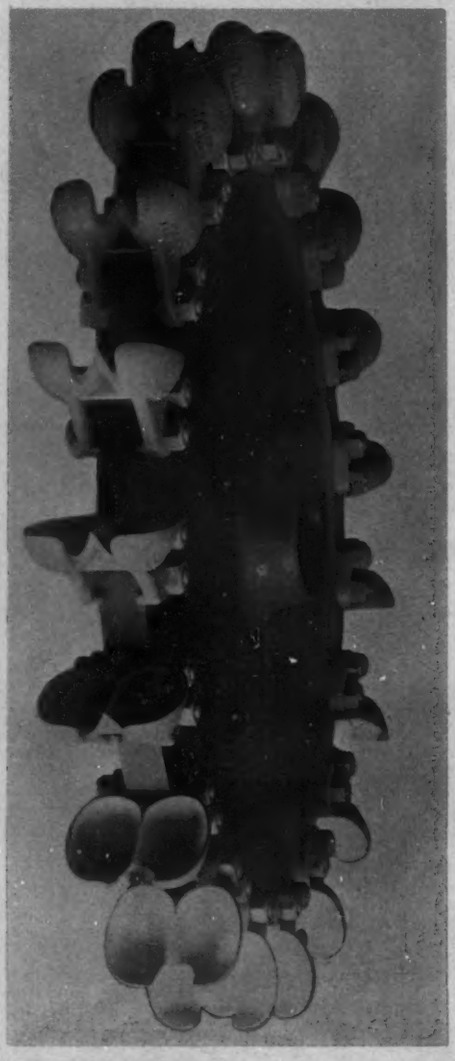

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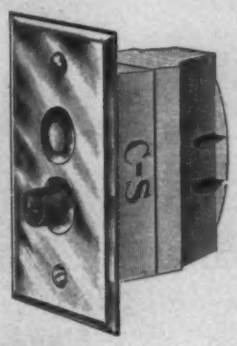

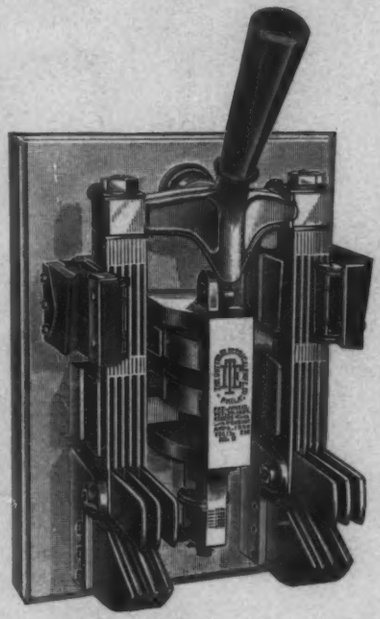

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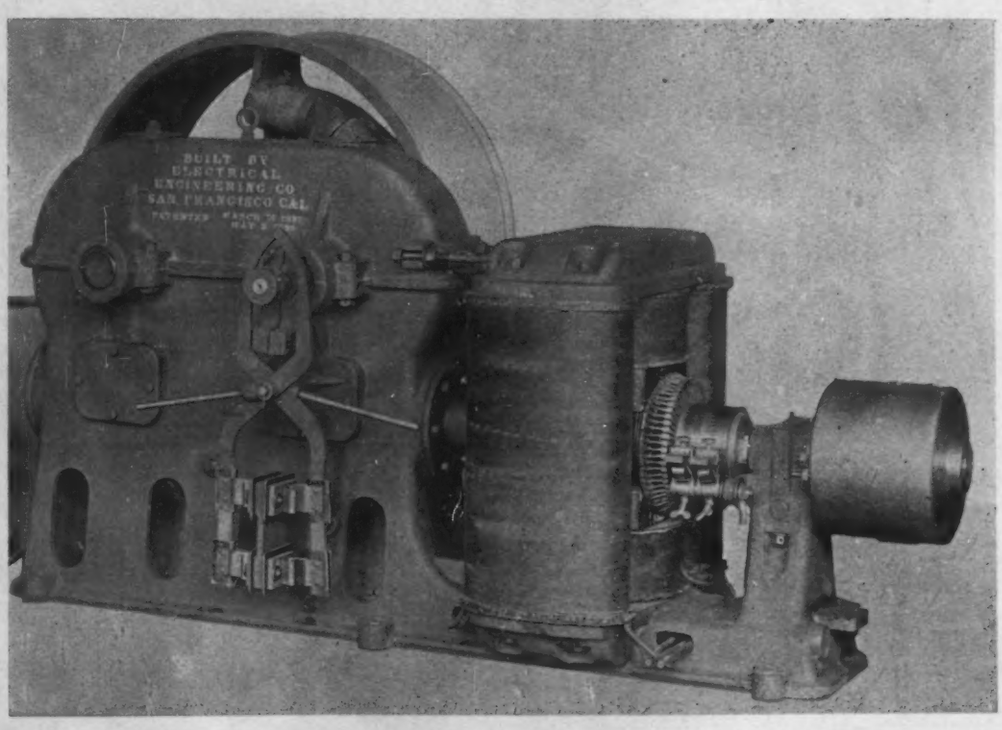

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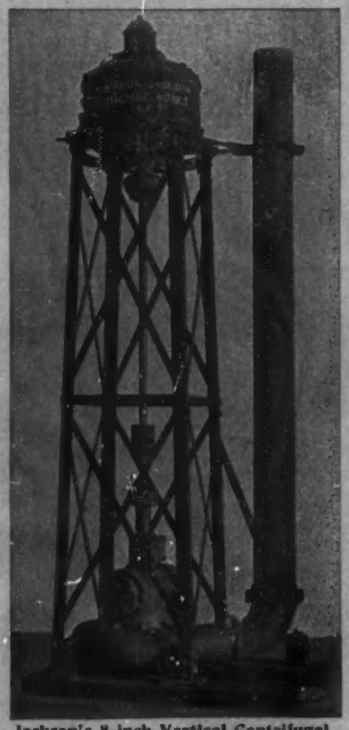

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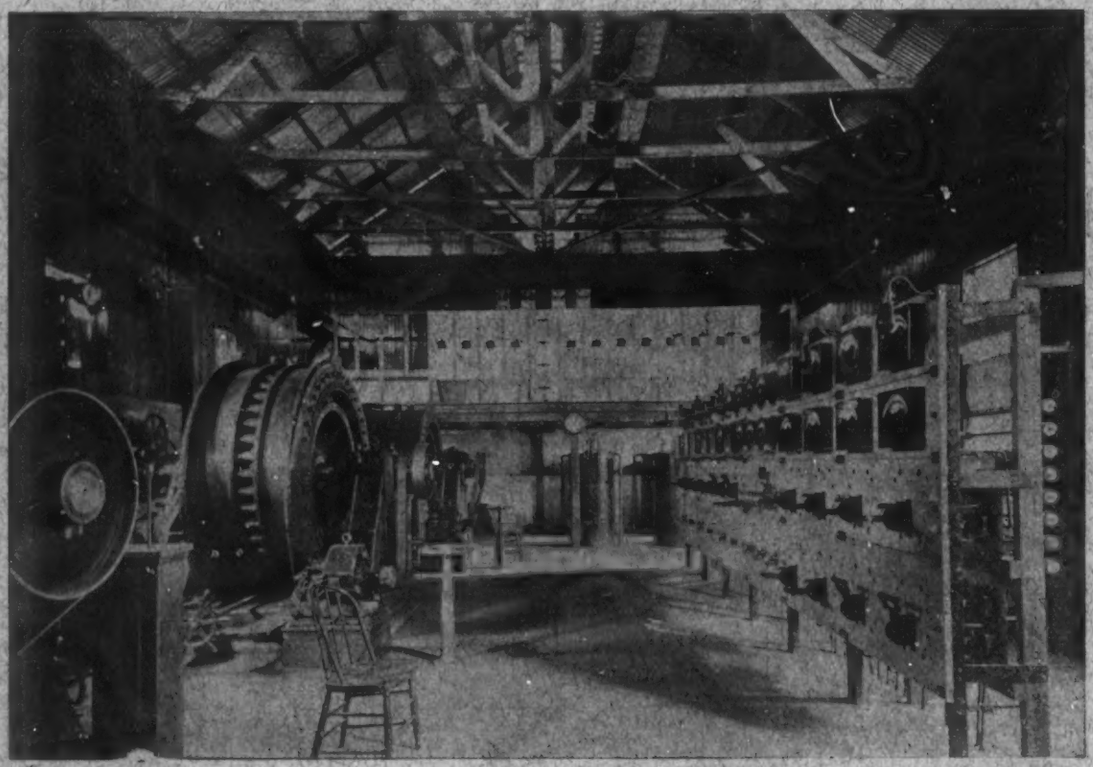

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